AD

Research and Development Technical Report

ECOM-0472-F

# ADVANCED INTERCONNECTION AND PACKAGING TECHNIQUES FOR INTEGRATED CIRCUITS

## FINAL REPORT


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AD900546

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RAYTHEON COMPANY

MISSILE SYSTEMS DIVISION

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TR ECOM-0472-F
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1 JULY 1969 TO 31 JULY 1970

CONTRACT NO. DAAB07-69-C-0472
DA Project No. 1H6-62705 A-440, Task 01

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For
U.S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, N.J.

# ABSTRACT

The purpose of Phase I (Sections 1 through 5) of this program was to design, develop, fabricate, and test advanced interconnection and packaging techniques for complex hybrid microassemblies. The vehicle for accomplishing this objective was a package which accommodates a 1 x 1 in. working area, permits hermetic sealing without damaging the microcircuits mounted within this working area, and structurally withstands operating temperatures ranging to 350°C. The package must demonstrate a hermeticity of $10^{-8}$ cubic centimeters per second.

The contractor initiated the program by selecting an approach which takes advantage of the strength and impervious nature of fired multilayer ceramic; the adhesion and high temperature durability of refractory metals fired in a reducing atmosphere; the hermeticity of welded metal-alloy covers; and the inherent reliability which results from the use of buried vias (feed-through conductors).

Results accomplished in this study include: design and fabrication of two packages in which: 1) a separable ceramic substrate can be attached to the floor of the multilayer ceramic base with a metal lid sealed to the base, and 2) a metallized multilayer ceramic substrate with the metal lid sealed directly to the base; evaluation of laser, electron beam and parallel-seam welding sealing methodologies; development of production processes for the cover fabrication, attachment of the separable substrate, thermocompression chip and wire bonding and package assembly; and a reliability evaluation of the developed packages.

Finally, in Phase 2 (Sections 6 through 10) of this program, the separable ceramic substrate package and lid were redesigned and the parallel-seam welding process was modified to "optimize" the sealing yield and corrosion resistance of the 1 x 1 in. working area hybrid circuit package. A 98.5 percent sealing yield was obtained for this redesigned parallel-seam welded package.

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PHASE I

# 1. PROGRAM OBJECTIVES

The objective of this program is to develop and optimize packaging techniques and configurations for establishment of approved packages for U. S. Army use which will provide low-cost, reliable, and hermetic environmental and mechanical protection for complex hybrid microassemblies. The Technical Guidelines of the contract outline the specific steps which shall be taken in conducting this development program, including investigation and evaluation of the state-of-the-art sealing techniques, selection and optimization of the most promising sealing techniques, development and evaluation of enclosure configuration designs, and evaluation of reliability, producibility, and cost of the optimized sealing technique and enclosure package configuration. Sealing techniques to be investigated will not subject any electronic parts or circuits within the enclosure to a temperature in excess of 175°C and will provide a subsequent seal capable of maintaining mechanical stability and hermeticity at temperatures up to 350°C.

Enclosure configuration designs to be studied are as follows:

Type 1: A separable ceramic substrate attached to a ceramic or metal base of an enclosure with a ceramic or metal lid hermetically sealed to the base

Type 2: A metallized ceramic substrate with a ceramic or metal lid hermetically sealed directly to the substrate

# 2. APPROACH

The approach for investigation under this contract is based on fabrication of a multilayer ceramic package with buried-layer metallizations for electrical interconnections in the area beneath the sealed cover. After initial "green-state" lamination and firing, this design becomes a one-piece ceramic body with feedthrough conductors and a metallized area for welding or braze-welding a cover seal. Such a package will be highly reliable, because compatible materials and processing techniques are used.

## 2.1 Type 1 Package

The Type 1 separable ceramic package, illustrated in Figures 1 and 2, has been fabricated using state-of-the-art techniques employing a molybdenum-manganese conductor pattern buried within a multilayer ceramic substrate, with a metallized shelf area for welding or braze-welding an F-15-type alloy lid. External connection is made through gold-plated 0.017 x 0.005-inch ribbon F-15-alloy leads brazed to the substrate metallization along the "shelf" area outside the hermetically-sealed volume. The internal bonding pads are nickel- and gold-plated, so that conventional assembly techniques can be used.

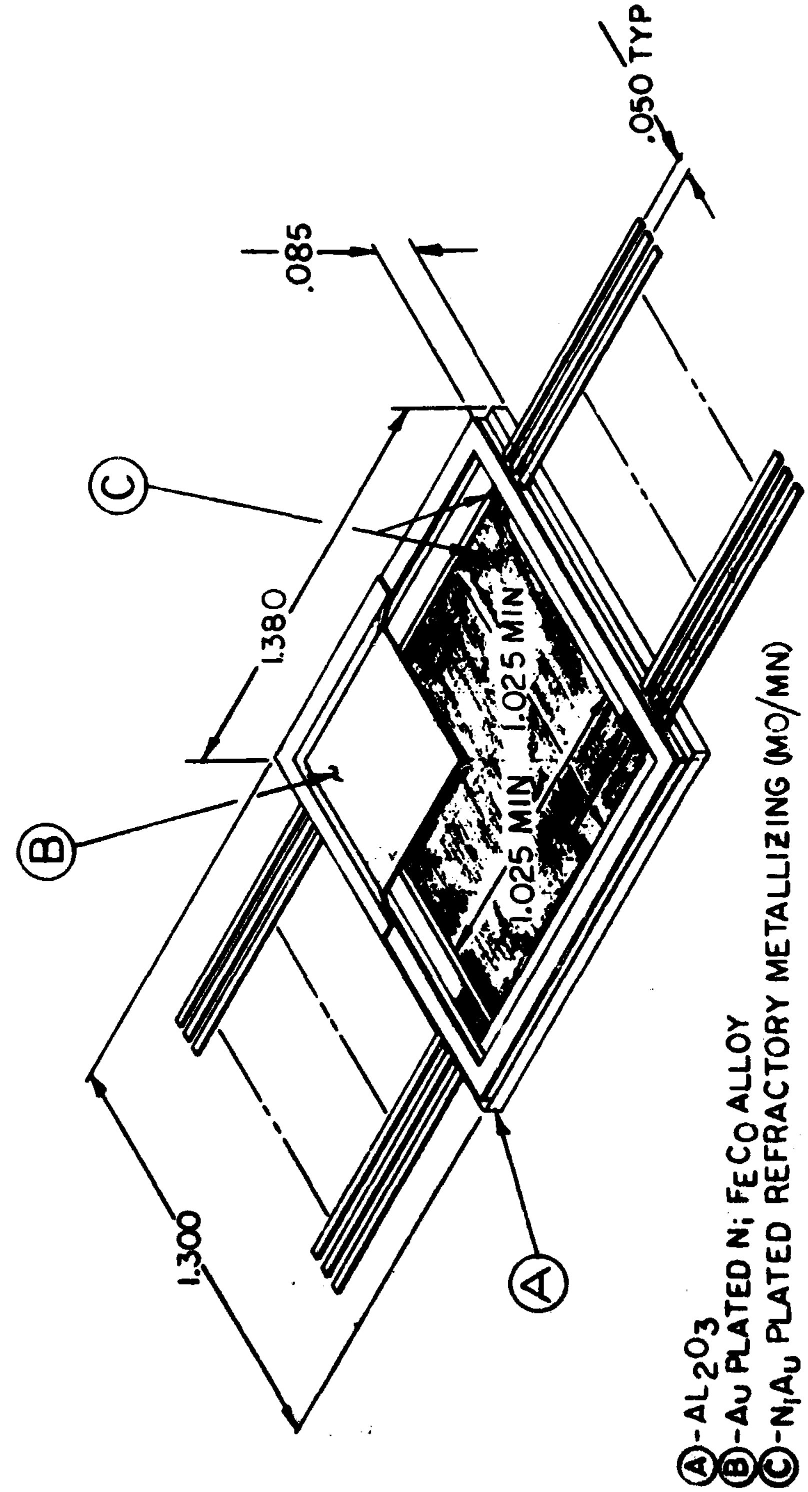


**Figure 1 - Type 1 Package**

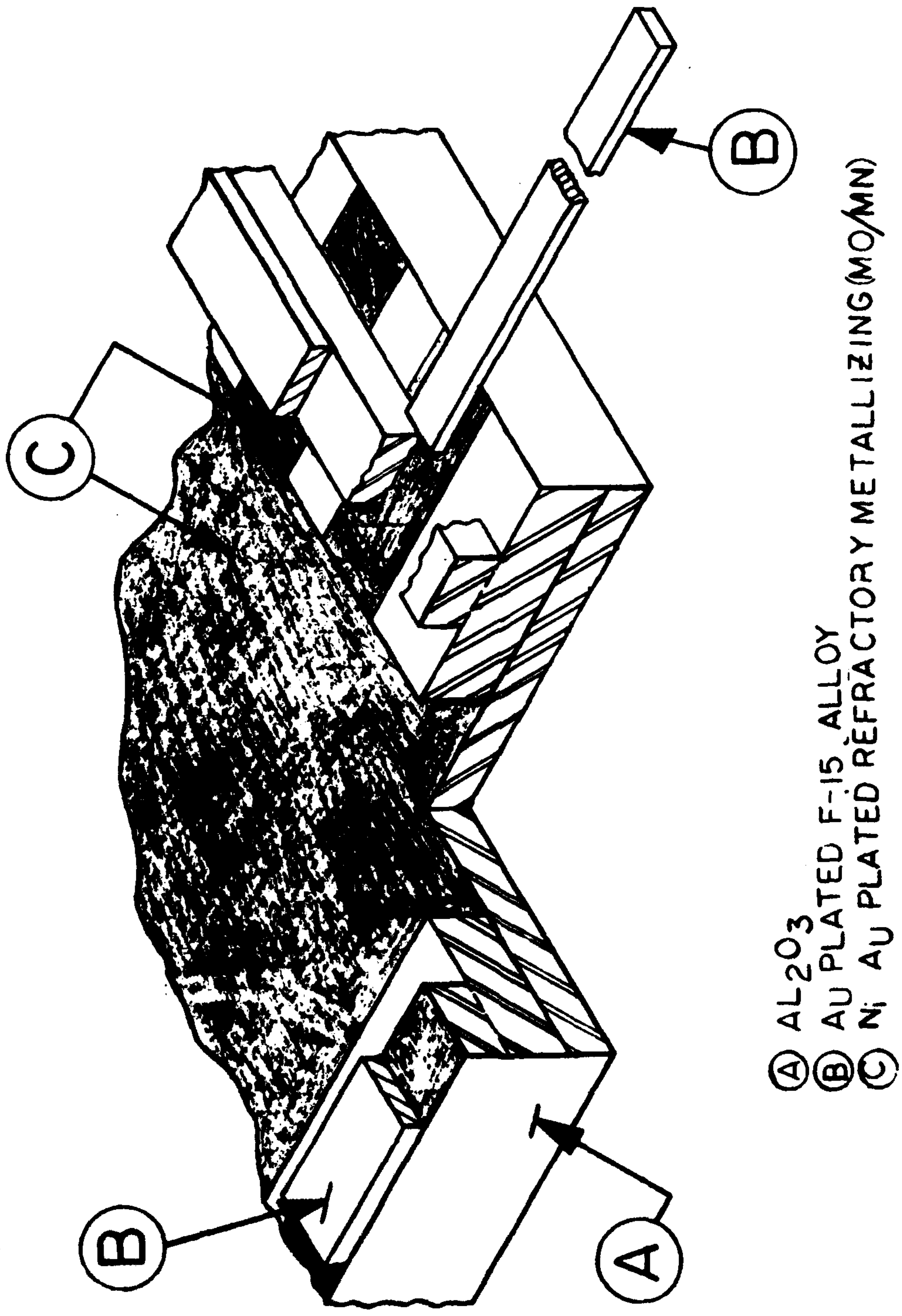


**Figure 2 - Type 1 Package - Cross Section View**

Figure 3 details the basic layers and elements involved in the separable-substrate-type ceramic package. The following fabrication sequence is followed:

1) The ceramic tape is punched, metallized with a screen-printed molybdenum-manganese coating, and assembled to generate the package.
2) The assembled layers of ceramic tape are pressed together and fired at approximately 1600°C to provide a monolithic structure with discrete molybdenum-manganese conductors embedded in the ceramic to provide feedthroughs and surfaces for eventual lead, substrate, and cover-collar attachment. Then nickel is plated on and sintered at 1100°C into the molybdenum-manganese metallization to provide a more-readily-brazable surface.
3) The F-15-alloy* leads and cover collar are brazed using a silver/copper eutectic fired at 800°C to the monolithic ceramic package base. The completed package base metallizations then are gold-plated.
4) The separable substrate, with a molybdenum-manganese nickel-gold-plated metallization is brazed to the package base with No. 525 alloy** in a reducing atmosphere of hydrogen at 600°C.
5) Active devices are gold-silicon-eutectic-bonded to the substrate metallization pads, and thermocompression wire bonds are made to interconnect the appropriate substrate metallization pads to the package and to the active devices using a 0.001 inch diameter gold wire.
6) The F-15-alloy cover is welded to the metal collar on the package to complete the hermetic enclosure.

### 2.1.1 Attachment of the Substrate to the Package

The separable 1 inch x 1 inch x 0.025-inch ceramic substrate must be attached to the ceramic base of package Type 1. Major requirements of the interface bond include:

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* F-15 - ASTM Specification F15-61T (Ni-Fe-Co)

** F-525 - Alpha Metals Co. (Au-Ag-Ge)

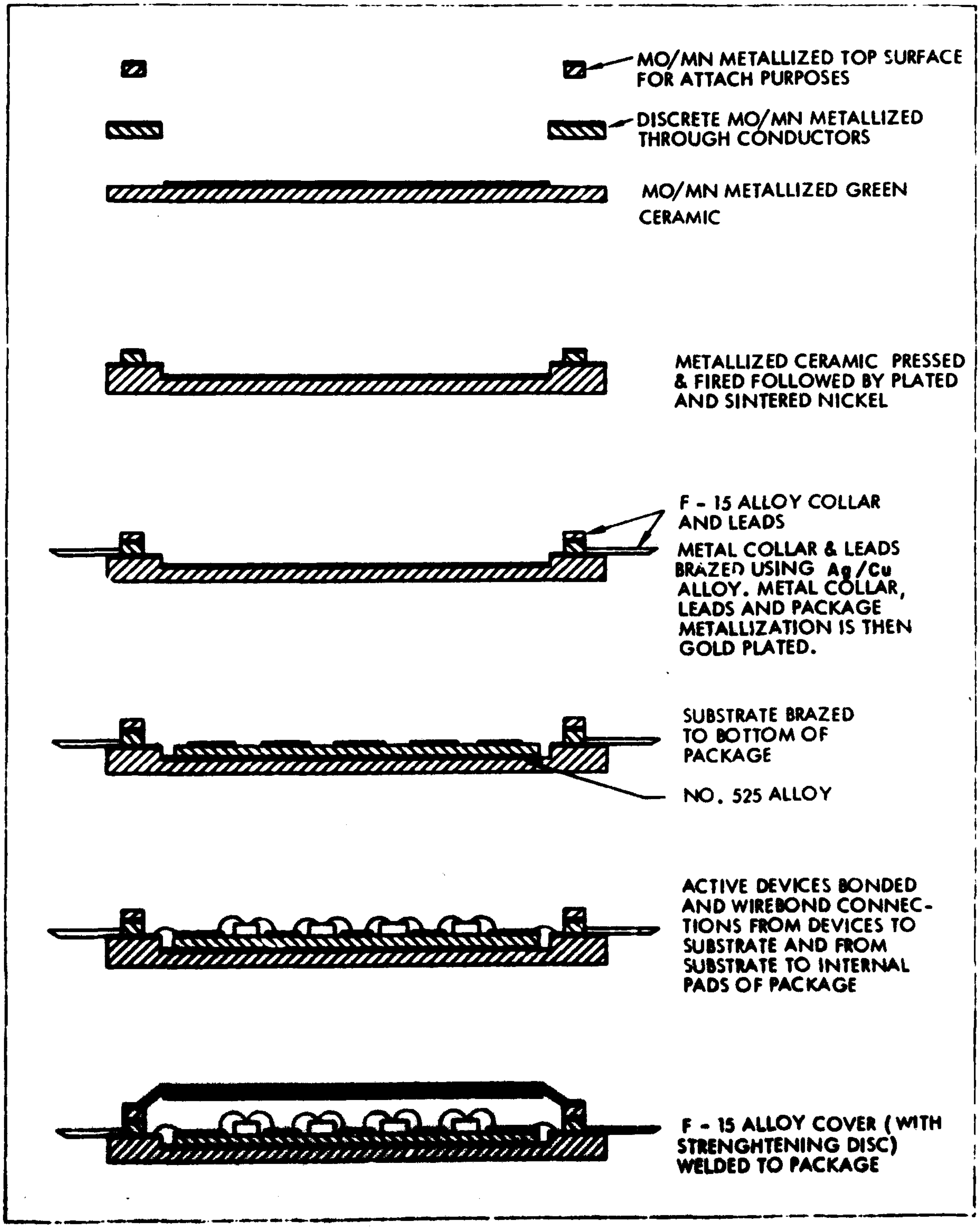


Figure 3 - Type 1 Package Assembly

1) The separable substrate must be positively attached to the ceramic base, so that the package will meet subsequent processing, package reliability, and qualification testing requirements.
2) The interface must provide good heat transfer to the package.
3) The bond must remain strong at a storage temperature of 350°C.

Substrate-package bonding methods evaluated during this program are:

1) Brazing with preforms
2) Gallium-copper intermetallics

Brazing is a proven reliable attachment method which requires a minimum of specialization. Both the bottom of the separable substrate and the package base are metallized with a molybdenum-manganese nickel-gold metallization prior to brazing with a No. 525 (gold-silver-germanium) alloy. This braze alloy will withstand subsequent die attachments, and also will allow the package to withstand the 350°C requirement.

The temperature requirements for this package also suggest the use of gallium intermetallic alloys as an alternate approach to substrate attachment. These compositions are soft and adhesive at room temperature for several hours after blending, yet without applied heat they spontaneously form a metal alloy which will withstand sustained high temperatures. An alloy of 60-percent gallium and 40-percent copper, cured for five hours at 100°C or 48 hours at room temperature, will withstand exposure to subsequent temperatures ranging to approximately 600°C.

## 2.2 Type 2 Package

The Type 2 metallized-ceramic-substrate package illustrated in Figures 4 and 5 is designed with an elevated package base (substrate or circuit-area platform) which is on an exposed plane above the leads and collar-sealing metallization. The exposed substrate or circuit plane, unique in this package design, may be completely metallized during the manufacturing process, so

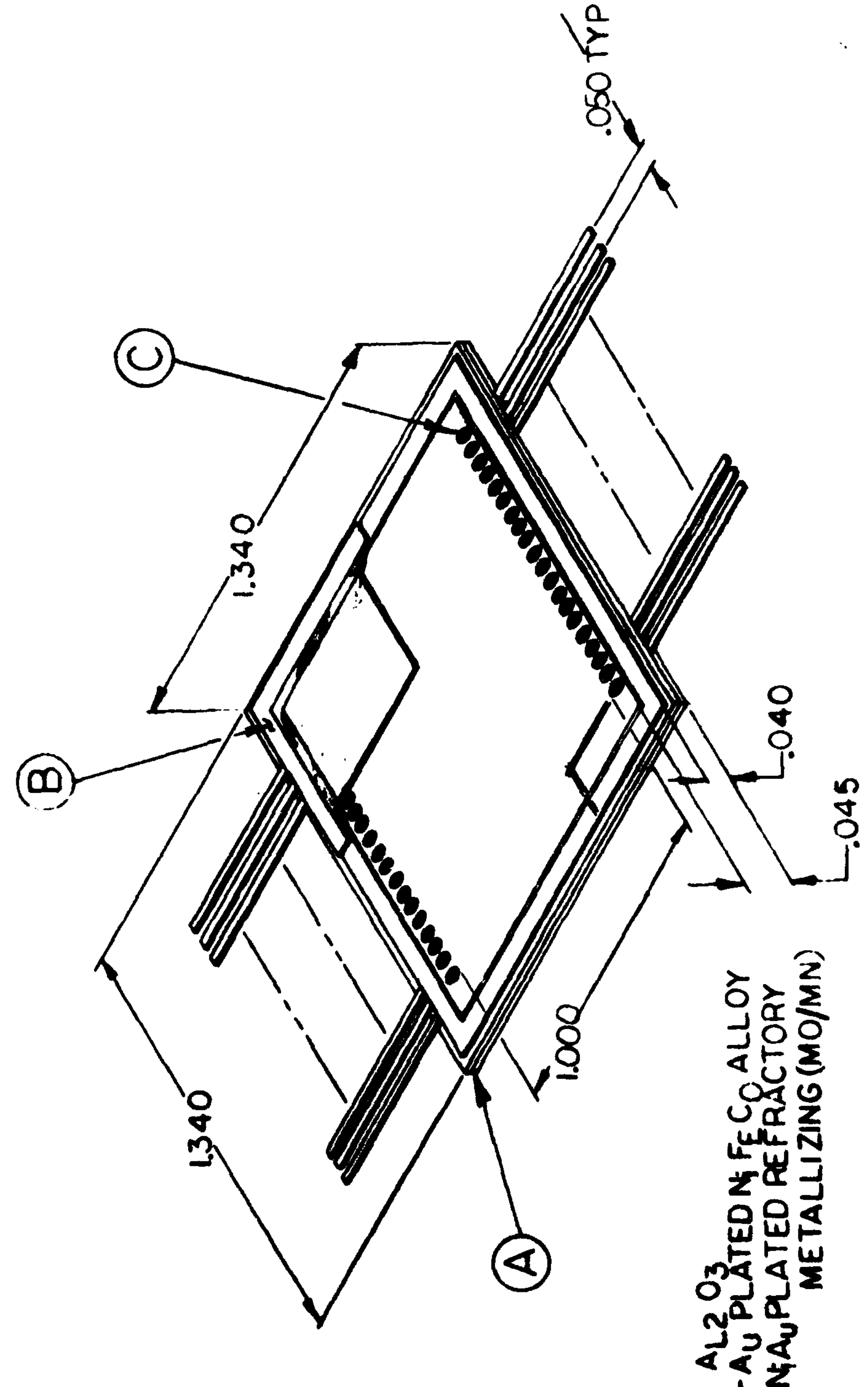


Figure 4 - Type 2 Package

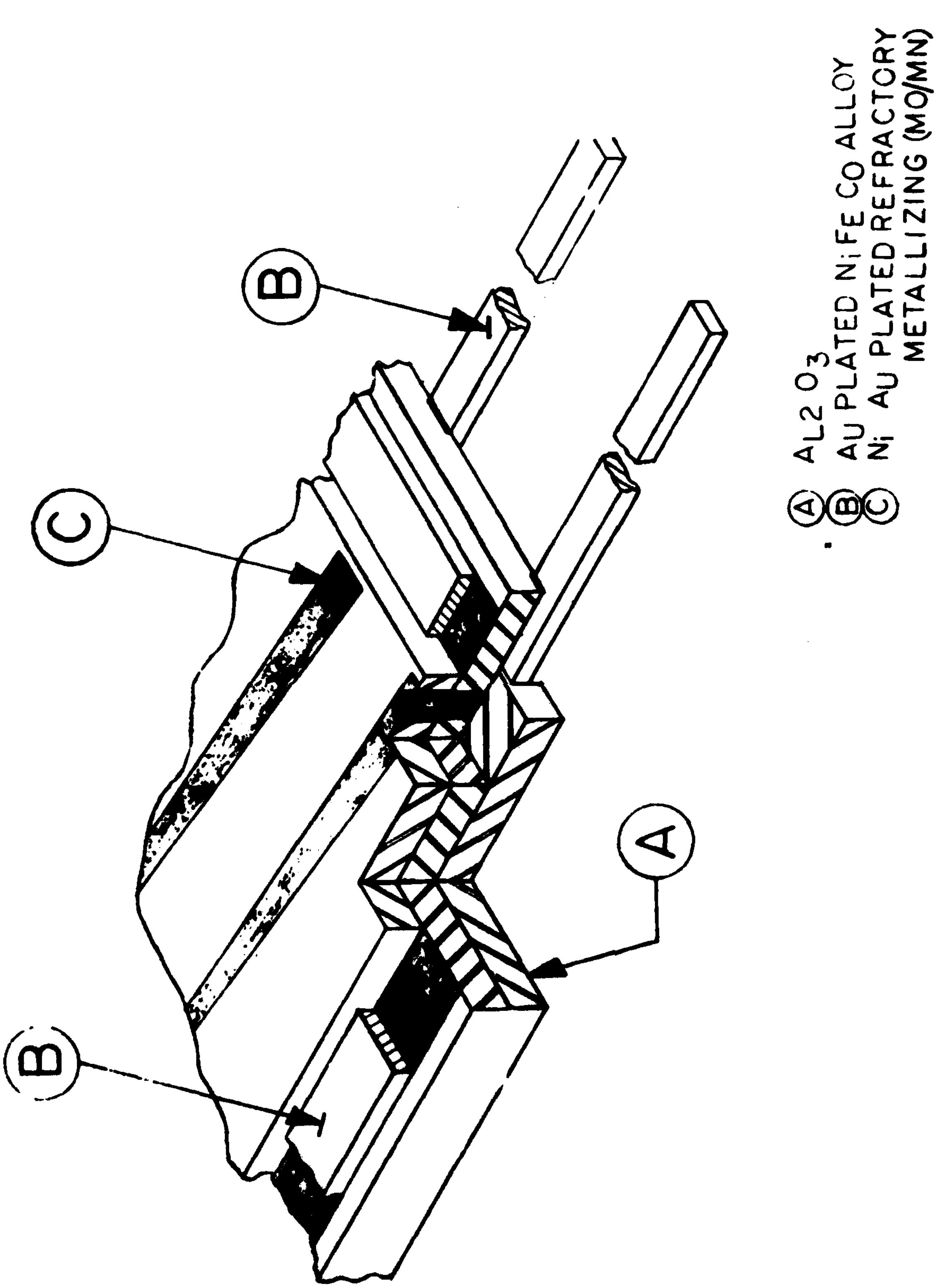


**Figure 5 - Type 2 Package - Cross Section View**

that it readily is accessible for subsequent photolithographic masking and etching to form the conductor pattern. Suitable substrate metallizations include molybdenum-manganese-nickel-gold and thin-film vacuum-deposited chromium-gold. Thick-film metallizations can be mechanically screened onto the surface; however, the completed package base with the brazed and plated lead frame and sealing collar should not be fired over 500°C in an oxidizing ambient to prevent oxidation of the molybdenum-manganese metallization, leads and sealing collar.

Package 2, like Package 1, is constructed of a three-piece laminated, selectively-metallized high-alumina (96 percent) ceramic monolithic structure, within which is buried a conductor interconnection system to provide electrical access from the internal ceramic platform or pedestal to the external package leads. The platform area is hermetically-sealed by welding an F-15-alloy lid to a metallized sealing-shelf area, as in Package 1. F-15-alloy plated leads are brazed onto the external pads located on the underside of the second ceramic layer as indicated in Figure 4, so that conventional package-mounting processes can be used. Unique features which will enhance the reliability and producibility of the Type 2 package include:

1) The external ribbon leads are located below the work surface platform and above the package mounting plane.
2) The vertical "vias" which interconnect the external leads to the internal platform are sealed since they are buried within the monolithic ceramic structure.
3) The three-layer ceramic laminate provides extra ruggedness.
4) The cover-sealing "shelf" is on a layer which is isolated completely from both the lead-attachment surface and the circuit platform surface.

The planned assembly sequence is shown in Figure 6.

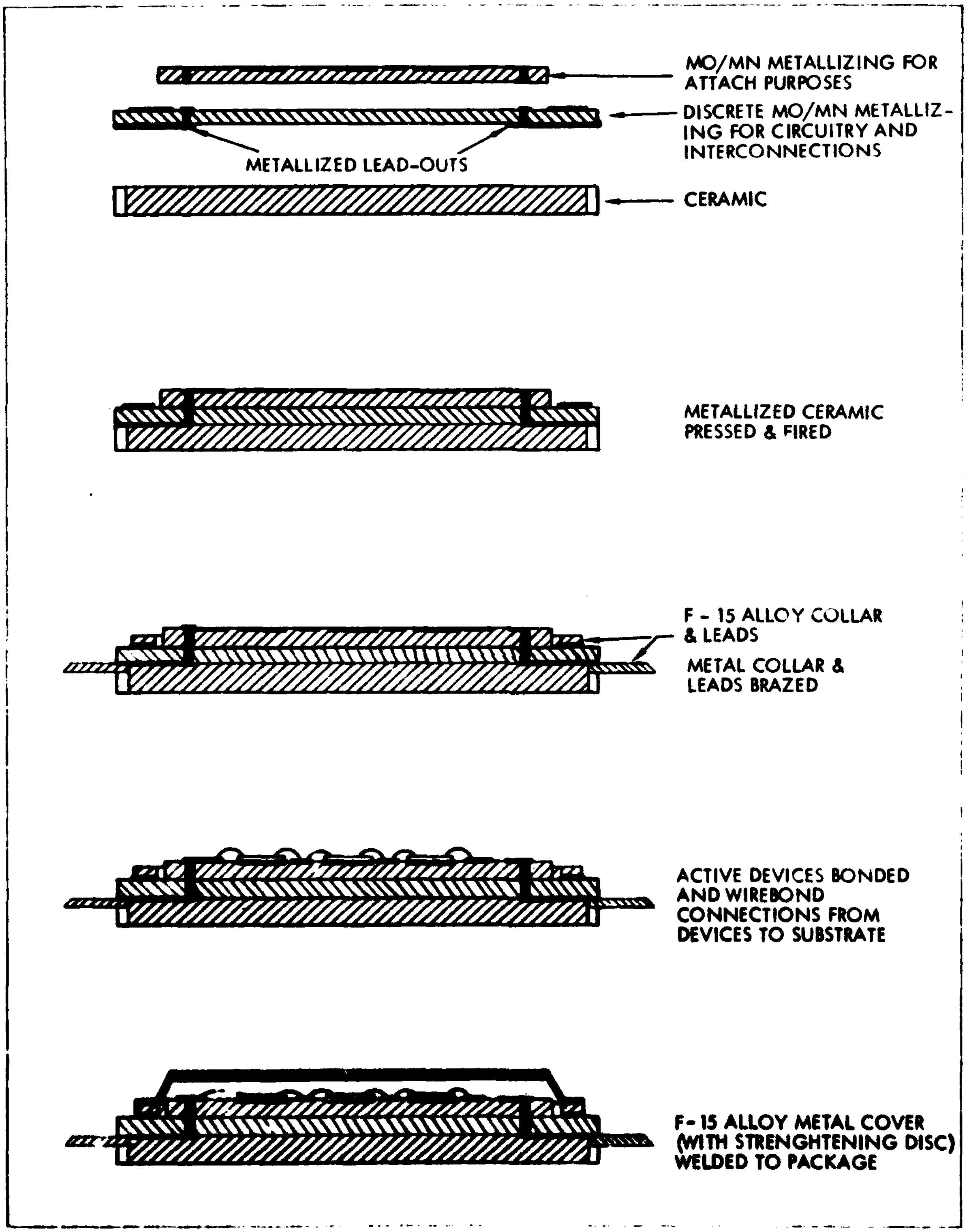


**Figure 6 - Type 2 Package Assembly**

1) Three sheets of high-density alumina ceramic tape are metallized with Mo/Mn, punched, and stacked to form the package. This multilayer ceramic body has conductor pads or terminals on the elevated (circuit) surface platform which is to be interconnected to the external leads by means of metallized Mo/Mn feedthrough holes and buried conductors.
2) After pressing the ceramic layers together, the assembly is fired at approximately 1600°C to obtain a monolithic ceramic package. The molybdenum-manganese metallization is nickel plated and sintered at 1100°C to provide a more-easily-brazable metallization.
3) The F-15-alloy lead frames and collar are brazed using a copper-silver eutectic fired at 800°C onto the package and gold plated.
4) Active devices are gold-silicon eutectic-bonded to the metallized and plated molybdenum-manganese pads originally screened and fired on the package platform. Thermocompression wire bonds then are made between the devices and the circuit metallization pattern using 0.001 inch diameter gold wire.
5) The F-15-alloy cover is welded to the window frame on the package.
6) Typical sheet resistivities of the metallization are: buried conductors <0.015 ohms per square, via feedthroughs <0.015 ohms per square, and top surface <0.001 ohms per square.

## 2.3 Sealing

Evaluation of the electron-beam braze-weld, laser braze-weld, parallel-seam braze-weld, and direct-metal-alloy-weld sealing methods has taken place, and suitable welds have been made by each of these processes. It can be concluded that high-energy localized heating sources are practical for sealing large laminated-ceramic packages, since such an operation does not require heating the entire package.

In this study, maximum effort is being aimed toward adapting the parallel-seam welder to the hermetic sealing of these packages. This technique has been successfully applied to the hermetic sealing of smaller packages, and preliminary results indicate that it also can be used for larger packages.

Parallel-seam welding is performed in a dry box filled with nitrogen (or nitrogen plus 10 percent helium) having a moisture content of 40 ppm or less. This atmosphere provides an ideal ambient for the package and its contents, which never are exposed to excessive temperatures during the sealing operation, since a localized heat source is used.

## 2.4 Covers for Package Types 1 and 2

The covers for package types 1 and 2 (Figure 7) are manufactured using a coined F-15 alloy 0.005 in. thick lid and a circular 0.007 in. thick disc brazed at 525°C using gold-silver germanium alloy to the inside. This cover will provide the required structural strength for the large area package while maintaining the thin flanges required for welding.

## 2.5 Reliability Evaluation

The test plan to be used in the reliability evaluation of package Types 1 and 2 is outline in Figure 8. All mechanical and environmental tests will conform to MIL-STD-883.

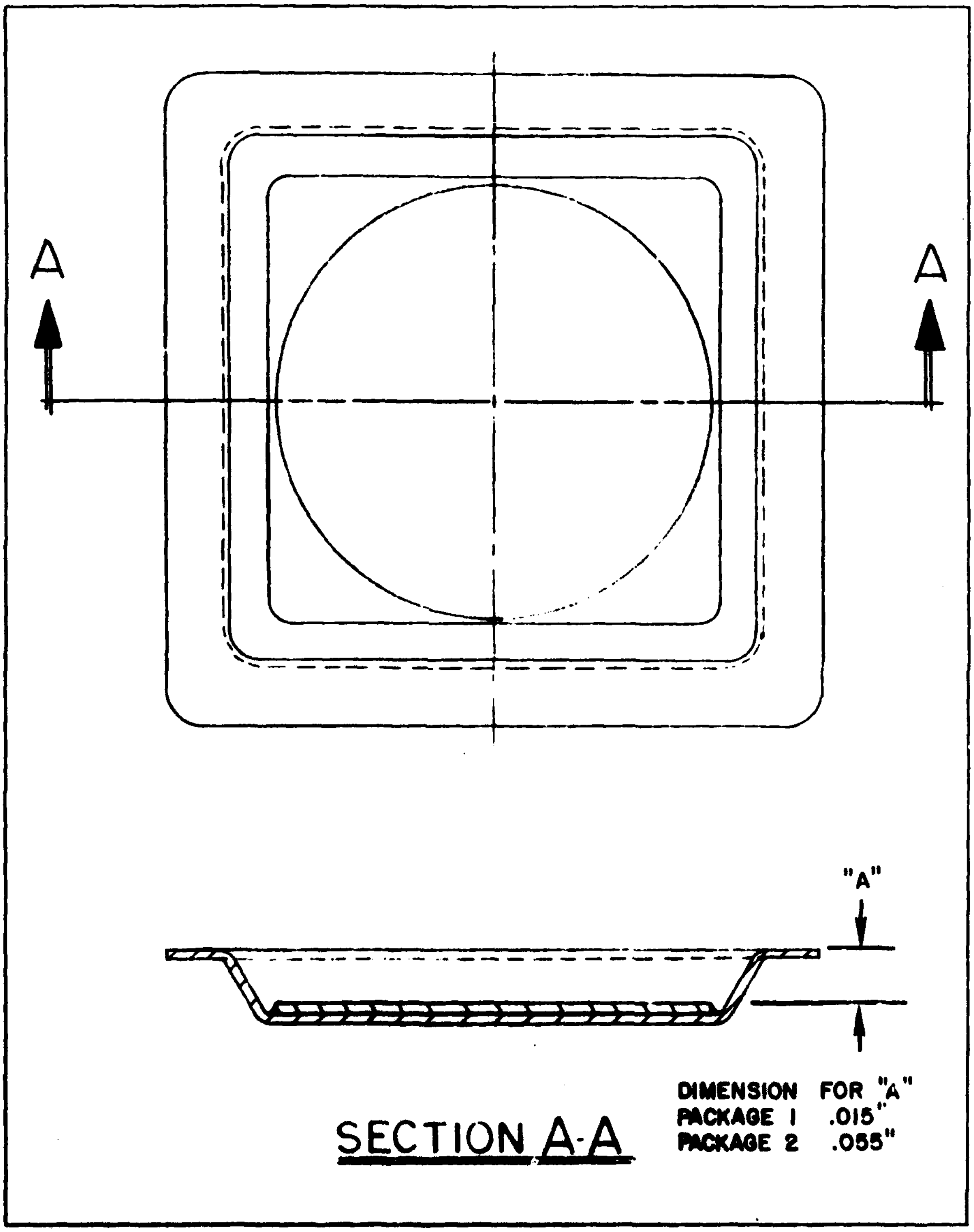


Figure 7 - Cover for Packages

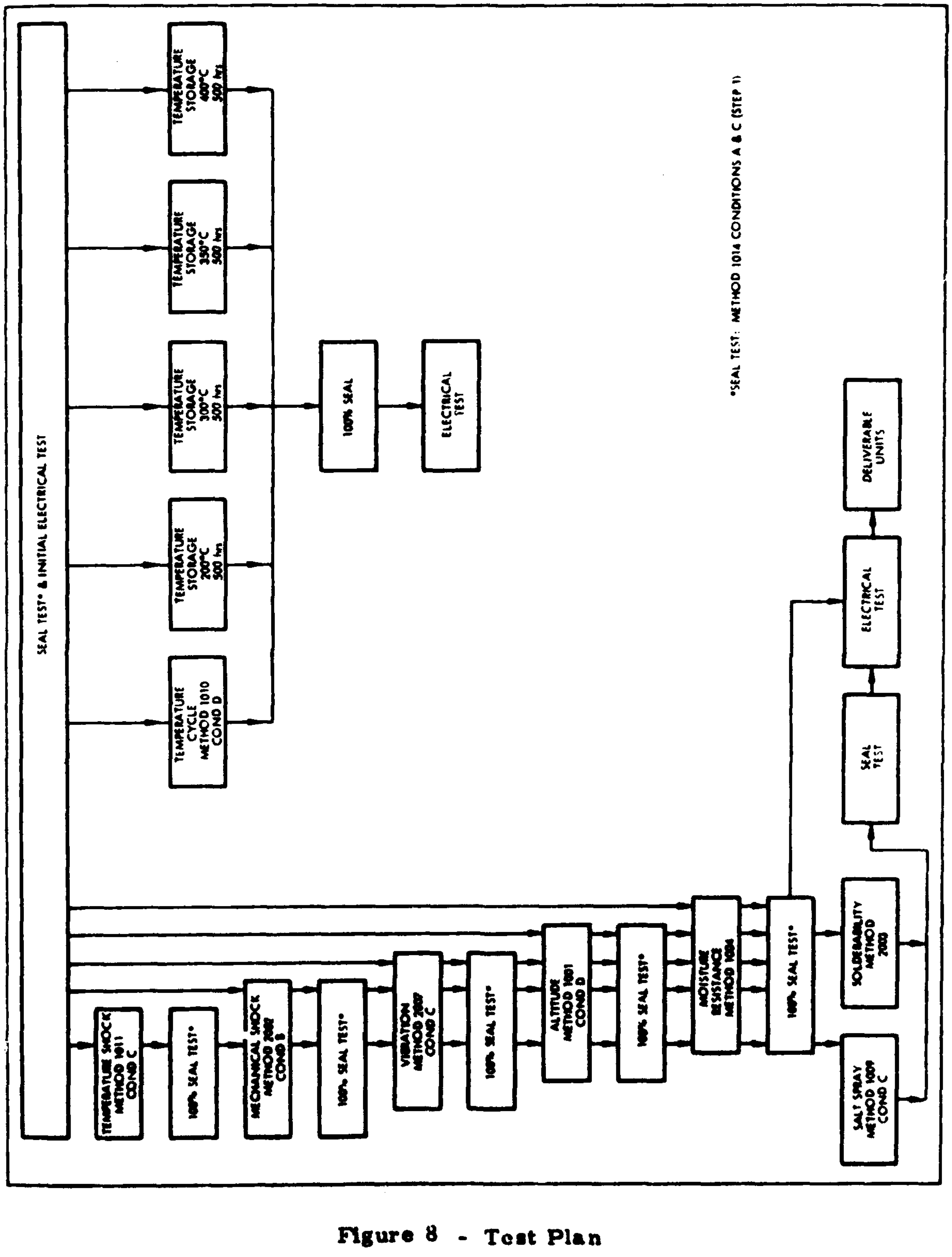


**Figure 8 - Test Plan**

### 2.5.1 Test Circuits

The test circuits will be separated into two groups:

1) Packages subjected to temperature cycling and high temperature storage (150)
2) Packages subjected to the qualification tests for delivery at completion of the program (160)

The first group of packages, to be subjected to temperatures cycling and high temperature storage up to 400°C, will contain one eutectic-bonded (inactive) semiconductor chip, and a series of internal thermocompression wire bonds which will provide continuity between six external leads.

The second group will have the following active devices: two digital SIC's (Raytheon Type RG-230 gate expander), one analog SIC (Type 709), and two diodes (Type 1N914). These devices were chosen for lead accessibility, in that they will enable direct testing o[illegible]ritical parameters (beta and leakage currents) without the interfere[illegible] of complex networks involving diffused resistors within the monolithic structure. A relatively simple molybdenum-manganese/nickel-gold conductor pattern has been used for interconnection of these devices. Thick or thin film resistors, or redundant intraconnections within the packages, will be avoided on these samples so that complex variables are not introduced, and the effective examination of failure mechanisms may take place.

Where electrical tests are indicated in the Test Plan, all units will be checked for beta, leakage currents, and/or resistance as applicable.

2.5.2 Test Procedure

After fabrication, an initial package hermeticity test and initial electrical tests will be performed as indicated in the Test Plan to confirm that all the packages under test represent usable product. The test methods to be used for hermeticity throughout the test sequence will be: Method 1014, Condition A and Condition C, Step 1 of MIL-STD-883.

2.5.3 Sample Size

The test lots for each of the two package types will be serialized and divided into subgroups as indicated in the Test Plan. These subgroups will undergo the test sequence as shown in the Test Plan.

2.5.4 Temperature Cycling

One subgroup of 50 units will be subjected to long-term temperature cycling per Method 1010, Condition D of MIL-STD-883. Package hermeticity and electrical tests (continuity) will be performed upon completion of this test.

2.5.5 High Temperature Storage

Four subgroups of 25 units each will be subjected to various degrees of temperature storage: 200°C, 300°C, 350°C, and 400°C. The test will last for 500 hours, with five samples from each subgroup removed at 200 hours, five samples removed at 300 hours, five samples removed at 400 hours, and the final ten samples in each subgroup removed after 500 hours.

2.5.6 Testing Sequence

The remaining tests will be performed in a particular sequence: Temperature Shock - Method 1011, Condition C; Mechanical Shock - Method 2002, Condition B; Vibration - Method 2007, Condition C; Altitude - Method 1001, Condition D; and where applicable, Moisture Resistance - Method 1004; Salt Spray - Method 1009, Condition D; Solderability - Method 2003; and Salt Spray - Method 1009, Condition C.

# 3. RESULTS

3.1 Design and Planning Study

3.2 Design and Assembly of Package Type 1

3.3 Design and Assembly of Package Type 2

3.4 Design and Fabrication of Covers for Package Types 1 and 2

3.5 Electron Beam and Laser Braze Welding

3.6 Parallel Seam Welding

3.7 Cost Evaluation

3.8 Test Evaluation

# 4. DISCUSSION OF RESULTS

## 4.1 Program Design and Planning Study

A review of the state-of-the-art in Microelectronic Packaging indicates that there are three major areas of technological deficiency, namely:

1) Interconnection vias from the substrate to terminations
2) Attachment of termination leads
3) Package sealing

These problem areas are discussed in more detail below.

### 4.1.1 Interconnection Vias from Semiconductor to Terminations

The T0-5 and T0-18-type packages with a glass-to-metal seal and with provisions built into the design for true metal-to-metal welding served the industry well until the development of complex and very dense monolithic circuitry outpaced packaging capability. The success of the welded-type enclosure is well documented by the early Polaris Missile guidance system, which was designed around the Type R-212 welded three-leaded T0-5 transistor package. As more complex circuitry was made available to the system designer, the flat-pack concept, with greater termination density, was developed at considerable sacrifice in lead-seal integrity.

When more than three or four termination leads are required, it becomes increasingly difficult to make reliable glass eyelet lead-seals. As the packages with these metal-framed glass eyelets are assembled to connectors, printed wiring boards, or terminal pads, unavoidable stresses are introduced in the glass seal, so that cracked glass eyelets result. This failure mechanism is further aggravated in glass sandwich-type seals, where the leads essentially are molded in glass between ceramic structures. Thin ribbon leads are very susceptible to failure at the glass, metal and air functions due to erosion and intergranular corrosion where it is difficult for the plating to provide adequate protection. The thermal expansion mismatch

between the glass, metal and alumina ceramic components make the resultant package subject to catastrophic failure from thermal or mechanical shock.

The multilayer, metallized-ceramic approach described earlier has been selected by this contractor to obtain reliable interconnection vias for complex microcircuits.

In this approach, the required interconnection patterns are screen-printed on green ceramic tape using a moly-manganese paste. Next, the tapes, from which appropriate cutouts have been made, are properly aligned, pressed together, and then fired in a reducing atmosphere at a temperature of approximately 1600°C. During this operation, a solid unit of ceramic is formed, which includes an integral conductor pattern.

The molybdenum-manganese metallized areas on the ceramic (shown in Figures 1 to 4) provide the brazing contacts for the nickel-iron-cobalt alloy sealing collar and the termination lead frames. This completes the basic package, a package containing no areas vulnerable to cracking of the vias which would result in loss of hermeticity, since all conductors are contained in one fused volume of ceramic.

As discussed earlier, package Type 1 is designed to accept a 1 x 1-inch substrate containing film circuitry, while package Type 2 is designed to provide an interconnection matrix of 1 x 1-inch inner dimensions on the upper surface (platform) of the package itself.

### 4.1.2 Attachment of Termination Leads

Package termination lead-attachment methods currently in use are of two basic types.

#### 4.1.2.1 Glass-to-Metal Seals

This type of construction employs a metal lead fused in a glass eyelet, which in turn is contained within a metal frame; or alternatively, a metal lead fused within a glass layer located between two pieces of either ceramic or metal. As discussed in Subsection 4.1.1, this type of structure is prone to glass-crack failures in multilead packages. Such approaches have been rejected by this contractor for the USAECOM program.

4.1.2.2 Terminations Brazed to External Pads

The termination pads provided in a buried-layer ceramic piece-part such as that described in Subsection 4.1.1 make lead attachment a one-step brazing process which in no way is connected with or has an influence on the hermeticity of the package. A multiple-lead frame can be fired to the metallization provided on the ceramic by using a braze media such as a 72 percent silver, 28 percent copper eutectic alloy with a melting point of 779°C fired in a hydrogen reducing atmosphere. The copper-silver alloy provide advantages of good welding characteristics, good bond strength and a sufficiently higher melting point to withstand all normal post processing temperatures. Typical peel strengths exceed 10 pounds for a 0.017 x 0.005-inch F-15 alloy lead on a 0.030 x 0.040-inch metallization pad and the alloy is available in electronic grade purity. This brazing technique has been selected for lead attachment.

4.1.3 Package Sealing

Package Types 1 and 2 both require materials of construction capable of withstanding step-stress testing at temperatures up to 350°C. With this specification in mind, the following sealing methods have been considered.

4.1.3.1 Ultrasonic Welding

This method utilizes clamping pressure on the metals to be joined, coupled with intense high-frequency vibration of a tool head at the site to be welded. The major advantages of this approach include relatively low sealing temperatures, and the absence of weld "splatter".

Successful application of ultrasonic welding techniques for this program, however, would require the use of relatively large flanges on the metal covers, and on a metal collar attached to the ceramic substrate, because the ceramic would be unlikely to withstand direct clamping pressures without cracking. The final result would be a cumbersome package. Further, there are possibilities that the quantity of ultrasonic energy required to effect

a metallurgical bond in the metal flanges could be sufficient to adversely affect the internal microcircuitry. For these reasons, ultrasonic welding was not pursued.

4.1.3.2 Cold Welding

The joining of overlapped metal surfaces can be accomplished by mechanical pressure through indentor dies operated at room temperature. As in the case of ultrasonic welding, large overlapping flanges are required for this process, and these are not practical within the specified design dimensions of the proposed packages. The hermeticity of a Kovar-to-Kovar seal joined by this method would be questionable, since the technique is primarily directed towards the joining of ductile nonferrous alloys, particularly alloys of aluminum and of copper. This method, therefore, is not amenable to the selected package design.

4.1.3.3 Electron Beam Welding

Localized melting of metal can be accomplished by focusing a beam of high-velocity electrons on a small spot on the workpiece. A continuous weld zone is formed by the movement of the workpiece under the electron beam; formation of a hermetic seal thereby is readily accomplished. The attainment of a very narrow weld is possible by this method, so that the danger of overheating the integrated circuitry within the package is greatly reduced. The quality of the weld is excellent, since it is formed at relatively low pressure within a vacuum chamber. Fairly complex and expensive fixturing equipment is required, however, to completely automate the process, and to hold the ceramic packages and covers for accurate positioning and movement beneath the electron beam.

The many advantages of electron beam welding warrant devoting a portion of the project time to this technique.

4.1.3.4 Laser Welding

This technique involves directing pulses of high-energy photons to the overlapping metal structures to be welded. Extremely fine focusing

and, consequently, a small weld zone is possible by this method, as with electron-beam welding. Unlike the latter, spot welds are formed by the laser pulses, and it is necessary to overlap these spot welds to achieve a hermetic seal. The method has advantages over electron beam welding in that vacuum chamber is not required, and the overall cost of the equipment is less. The linear rate of laser welding is less than that of electron beam welding, since an overlapping-pulse mode is used. Overall characteristics of the laser equipment, however, including production rates and costs, should be quite favorable toward the use of this approach in preference to electron beam welding. Laser welding techniques will be evaluated.

#### 4.1.3.5 Parallel Seam Welding

The rotary-gap type of equipment represents a relatively recent approach to microwelding technology. This equipment forms a continuous series of minute welds between the lid of a metal cover and a metal flange or collar joined to a ceramic substrate. Controlled pulses of ac power between two parallel roller-type electrodes causes localized heating at the contact areas. The heat generated is sufficient to cause melting, and a resultant fusion at the two metal interfaces directly below the two electrodes. Movement of the roller electrodes around the perimeter of the package results in the formation of a weld and hermetic seal. Because the power is pulsed in short bursts of from 5 to 50 ms, followed by an equivalent period of no power, the zone that reaches weld temperature is kept small, and the overall temperature rise of the mounted semiconductor devices can be kept well below the maximum limit of 175°C. Welding is performed in a controlled atmosphere, such as dry nitrogen, or preferably nitrogen-plus-helium to facilitate fine-leak testing.

The parallel-seam welding technology has the advantages of comparatively low equipment cost, rapid setup time, high throughput capability, and is being used successfully in the industry for small packages such as the flat-pack. This approach, therefore, will receive major emphasis during the program.

#### 4.1.4 Selected Work Approach

The major objectives of this contract are to develop a package and a sealing process capable of protecting semiconductor junctions during sealing operations, meeting a maximum leak rate of 1 x $10^{-8}$ cc per second, and exhibiting structural stability at 350°C. In keeping with this plan, this contractor has designed the Type 1 and Type 2 packages, and is purchasing the "glassless" piece parts from Metallized Ceramics Corporation, Providence, Rhode Island, in accordance with the design specifications. The major development effort under this program involves tasks which have not been accomplished in the industry; namely, the successful high-yield sealing of packages having a 1 x 1-inch working area.

In summary then, this contractor has embarked upon the following design approach:

1) Design packages to satisfy the requirements of both Types 1 and 2, using piece parts such as buried-layer ceramic substrates, collars, and lead frames purchased to satisfy the selected design specifications.
2) Fabricate appropriate test networks for package Type 1, attach these substrates to the ceramic package bases, and attach active components.
3) Evaluate electron-beam, laser, and parallel seam welding techniques, to yield a sealed package which meets specified requirements.
4) Using the results of these investigations, finalize the design of the Type 2 package, and purchase this package with the interconnection pattern as an integral part of the substrate. Attach active devices.

### 4.2 Design and Assembly of Package Type 1

The multilayer ceramic with buried-layer metallizations for electrical interconnections Type 1 package shown in Figure 9 is designed to accept a 1-inch square 0.025-inch thick separable substrate. Dimensions of the package base, ceramic laminated layer thicknesses and the external lead

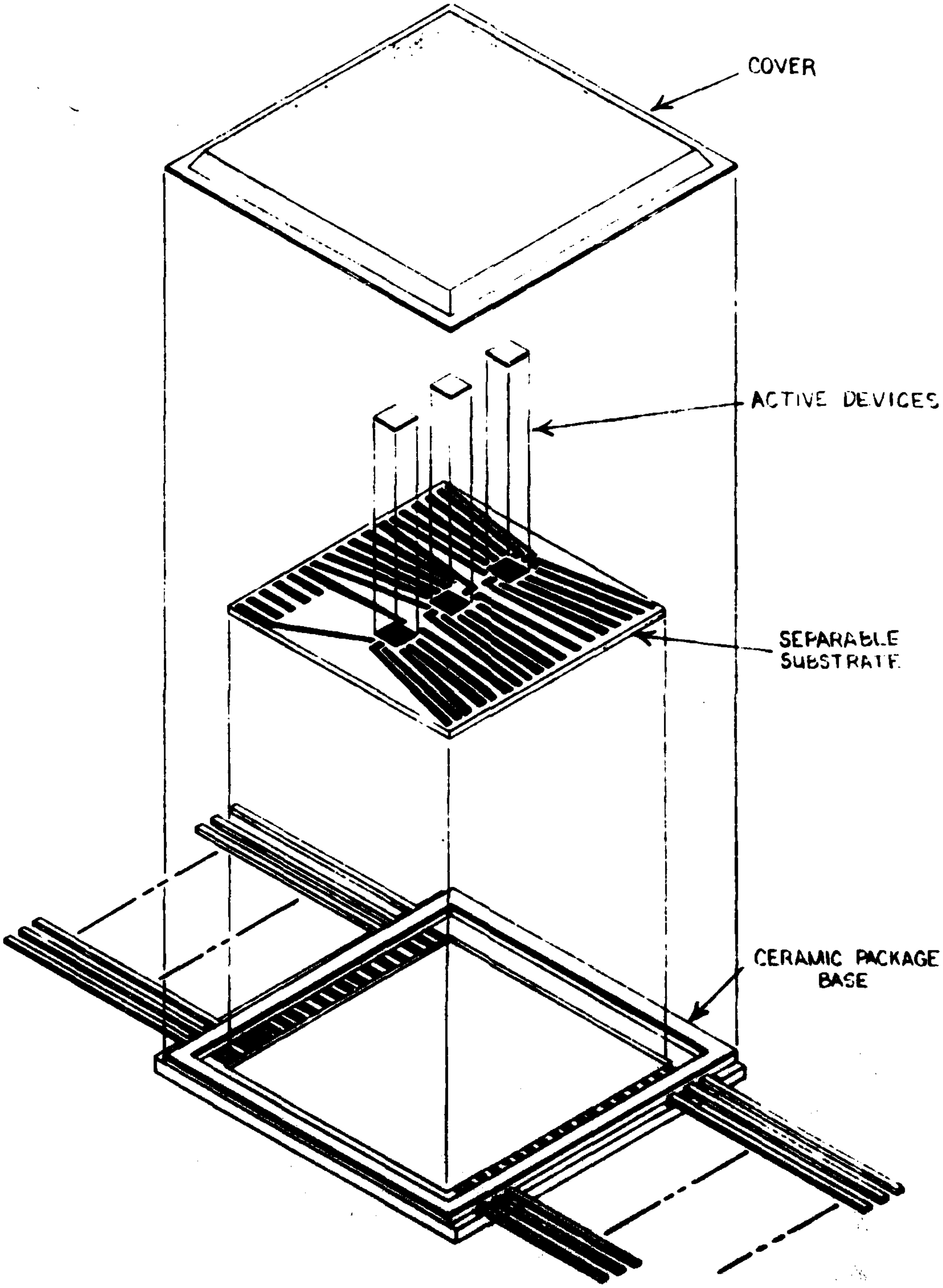


**Figure 9 - Type 1 Package Assembly**

frame bonding area were selected to be compatible with state-of-the-art ceramic technology. The multilayer ceramic base was manufactured by Metalized Ceramics Corporation, Providence, Rhode Island. The sealed package height of 0.115-inch was selected to provide a nominal inside height clearance of 0.050-inch between the cover and assembled 0.025-inch thick substrate.

For the reliability evaluation of this package, which required temperature storage at 350°C, a metallized as-fired 96 percent alumina substrate was brazed using a No. 525 alloy to the floor of the package.* The substrate was then interconnected to the package by thermocompression bonding 0.001-inch diameter gold wires to the conductive lands. Silicon active components were eutectic (gold-silicon) bonded and wired with thermocompression bonded 0.001-inch diameter gold wire. The metallized separable substrates were purchased from Metalized Ceramics Corp., Providence, Rhode Island with the screen-printed test pattern of molybdenum-manganese metallization subsequently nickel and gold plated.

The processing sequence shown in Figure 10 and described in subsequent pages has been established for the fabrication of the Type I test packages.

* The number 525 alloy, manufactured by Alpha Metals, Inc., Jersey City, New Jersey was selected because of the 525°C melting point which is well suited for brazing nickel and gold plated component assemblies before significant alloying can occur.

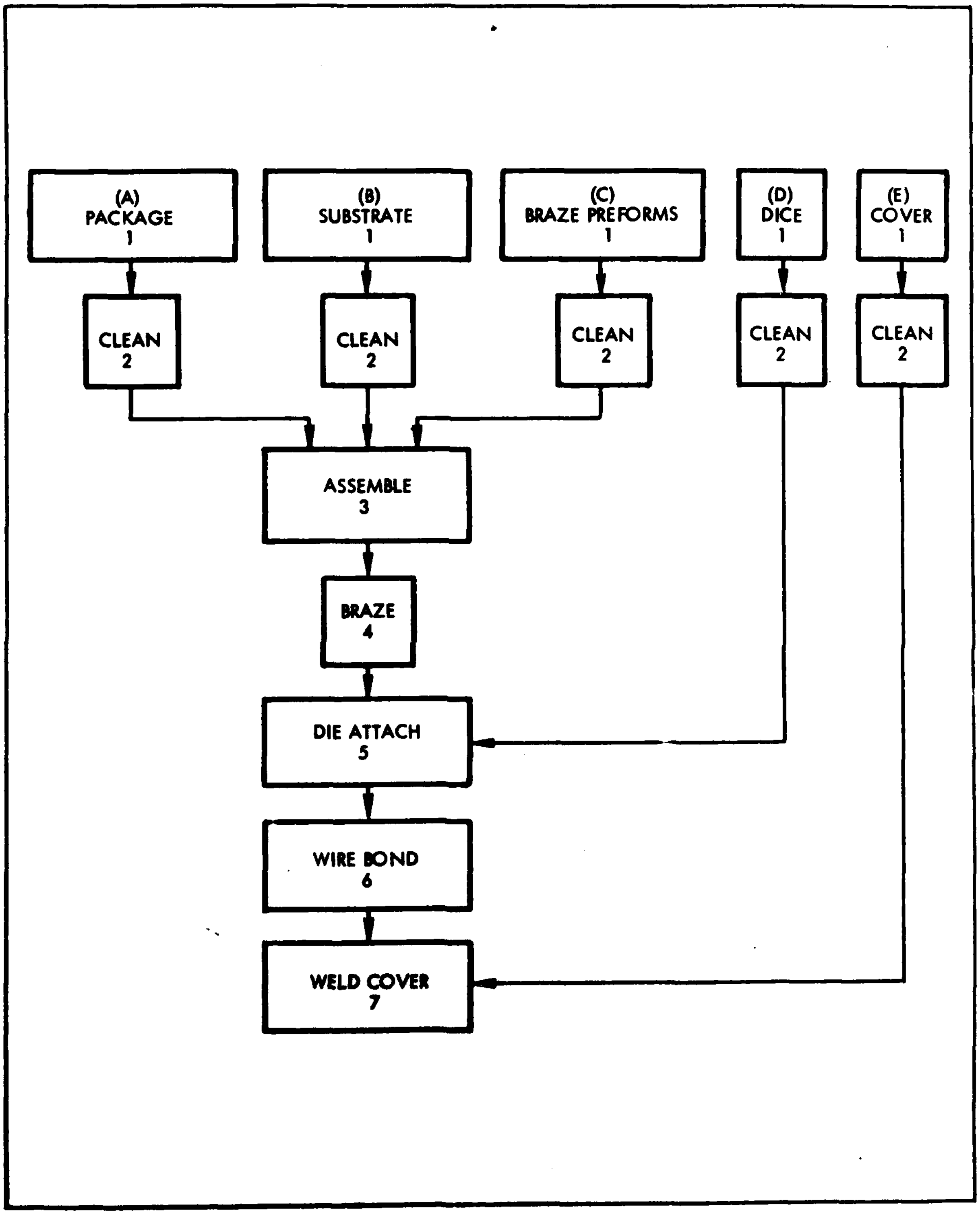


Figure 10 - Type 1 Package - Process Sequence

## PROCESS SEQUENCE

1. Materials

   1.1 Package Type 1 - Drawing Number AG8769

   1.2 Substrate Drawing Number EWC1120693

   1.3 Braze Preforms - No. 525 alloy 1/4-inch x 1-inch x 0.002-inch or equivalent

   1.4 Active devices 1 - RG-230; 1 - 2N709; 2 - 1N914

2. Clean - (package, substrate, braze preform, die, covers)

   2.1 Five-minute soak in Trichlorethylene

   2.2 Rinse in Acetone

   2.3 Rinse in Alcohol (Isopropyl)

   2.4 Rinse in Alcohol (Isopropyl)

   2.5 Dry

   2.6 Store in clean, dry, dustfree, covered containers

3. Assemble

   3.1 Place five braze preforms in the bottom of the package, one in the center and one in each corner

   3.2 Place substrate, circuit side up in bottom of package on preforms

   3.3 Place assembled package in furnace tray and weigh the substrate

   3.4 Store assembled parts in the clean, dry box

4. Braze

   4.1 Fire assembled packages at 560°C ± 10°C for three minutes in a reducing (dissociated Ammonia) atmosphere

   4.2 Store brazed parts in a dustfree storage cabinet

5. Die Attach

   5.1 Preheat package on a hotplate to 150°C ± 010°C

   5.2 With tweezers transfer prewormed package to heat column set at 425°C and flushed with Dry Nitrogen

   5.3 Ultrasonic scrub die

   5.4 Remove from heat column

   5.5 Store in a clean dry container

6. Wire Bond

6.1 Place package or heat column set at 200°C

6.2 Thermocompression wire bond devices attached to the substrate and package terminals

6.3 Remove package from heat column

6.4 Store in a clean, dry, storage box

7. Weld Cover

7.1 Mount package in welding fixture

7.2 Align the cover on the package and clamp in place

7.3 Advance welding fixture until it engages drive worm

7.4 Settings for welding the cover are:

Atmosphere - $N_2$ with less than 40 PPM moisture

| | |
|---|---|
| Peak-to-peak current | 600 amperes |
| Pulse duration | 20 milliseconds |
| Pulse repetition period | 60 milliseconds |
| Sensitivity circuit | 21 |
| Feed rate | 36 |

7.5 Unload the package when the welding fixture returns to the starting position

## 4.3 Design and Assembly of Package Type 2

In package Type 2 (shown in Figure 11), the multilayer ceramic with buried-layer metallizations for electrical interconnections from the internal circuitry to the external lead is both the package base and substrate. In order to facilitate microcircuit processing such as possible photolithography masking, etc., on the package base, the 1-inch square substrate area is raised 0.005-inch above the metal ring to which the cover is hermetically sealed. This substrate area contained a screened test pattern with a molybdenum-manganese, nickel gold-plated metallization. Silicon active chips were eutectic (gold silicon) bonded to the substrate metallization and wired with a thermocompression bonded 0.001-inch diameter gold wire. The assembled package height of 0.110-inch was selected to provide a nominal inside clearance of 0.050-inch between the cover and substrate base. Dimensions of the package base, ceramic laminated layer thicknesses metallized feedthroughs were selected for compatability with the current state-of-the-art ceramic technology. The multilayer ceramic base used in this program was manufactured by Metallized Ceramics, Inc., Providence, Rhode Island.

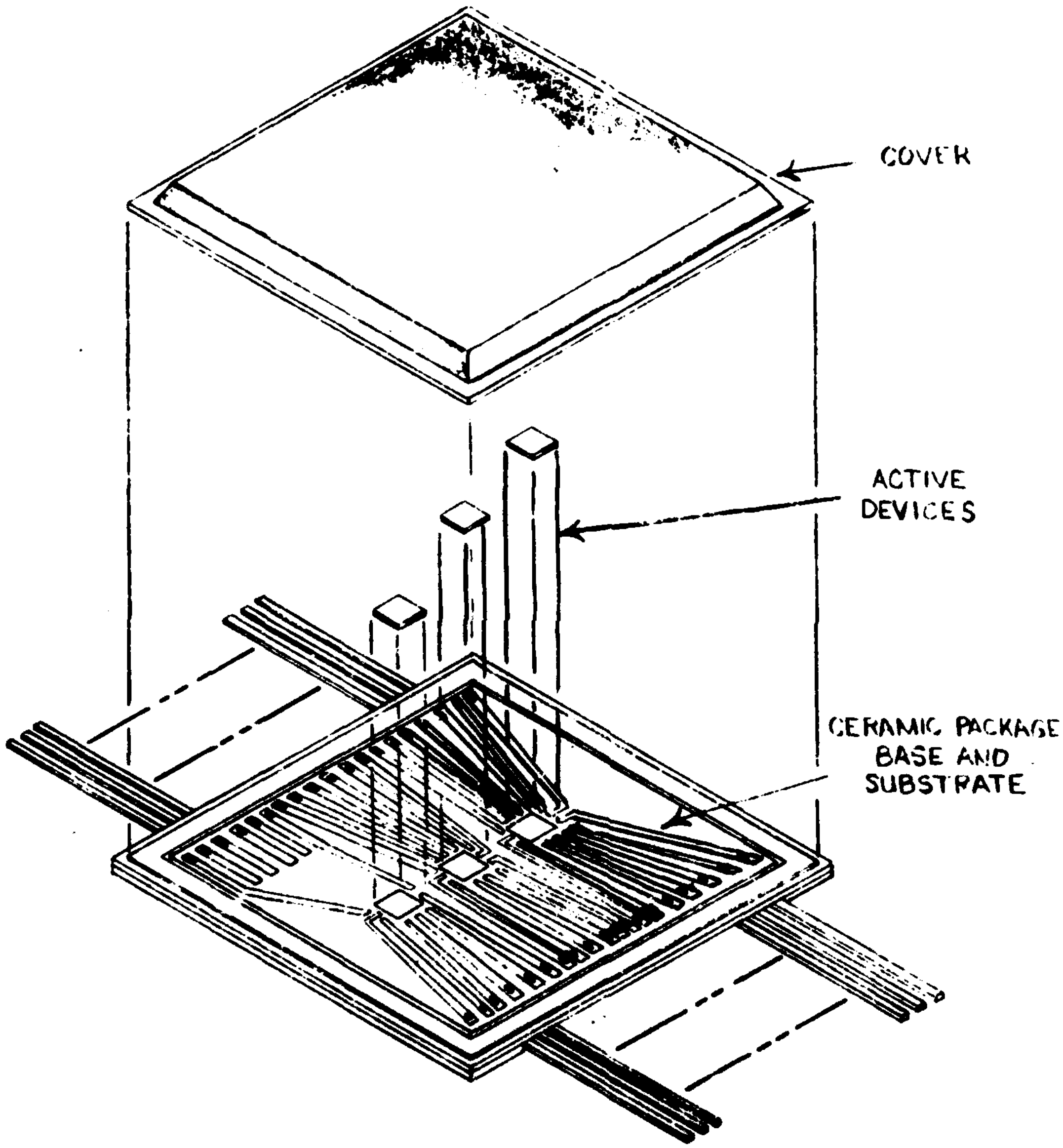


**Figure 11 - Package Type 2 Assembly**

The following processing sequence shown in Figure 12 and described on the subsequent page was used in the fabrication of the test packages.

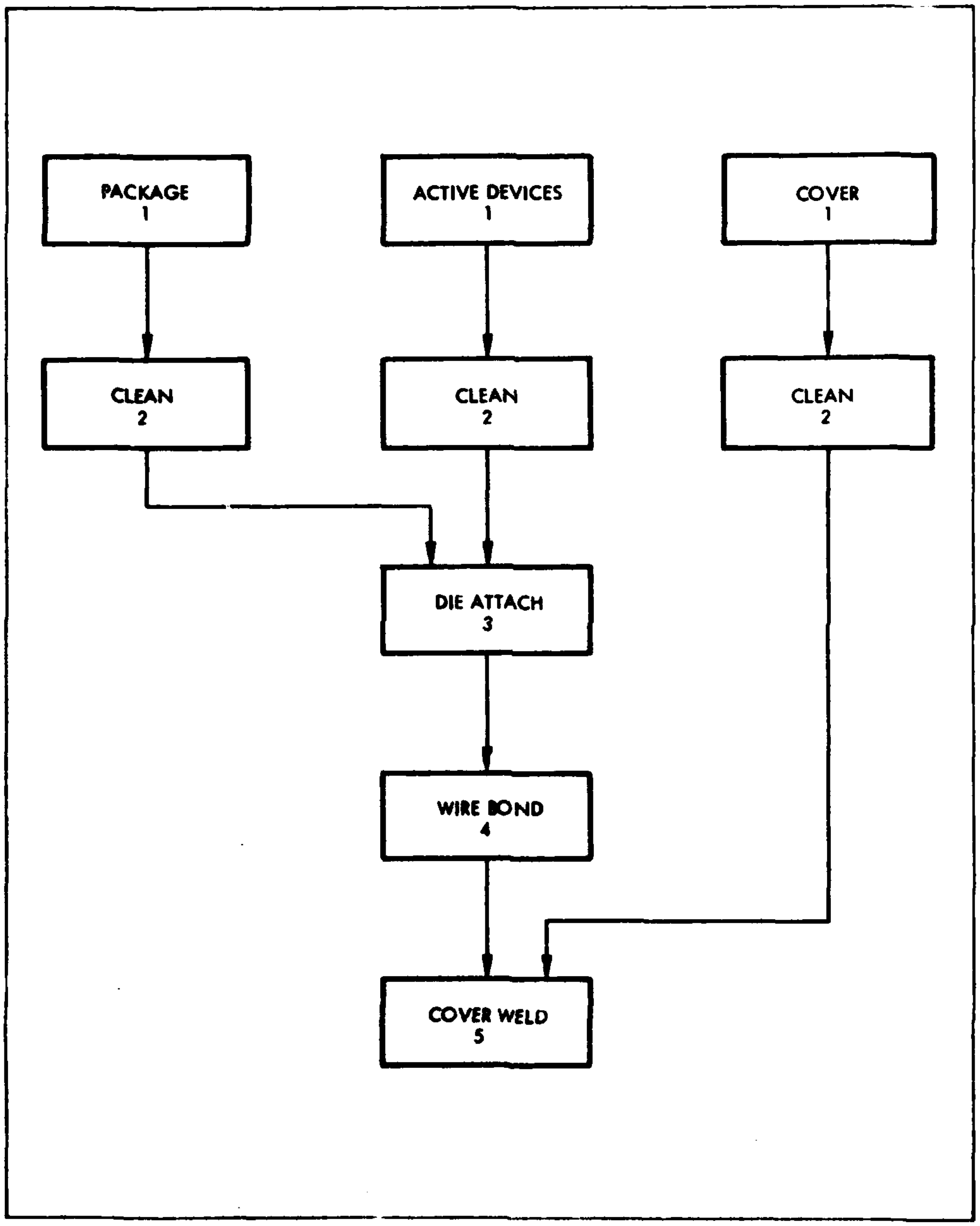


**Figure 12 - Type 2 Package - Process Sequence**

## PROCESS SEQUENCE

1. Material

   1.1 Package Type 2 (Drawing Number EWC1002694)

   1.2 Active Devices - 1-RG230; 1-2N709; 2-1N914

   1.3 Cover - Cover Assembly

2. Clean (packages, active devices and covers)

   2.1 Soak five minutes in Trichlorethylene

   2.2 Rinse in Acetone

   2.3 Rinse in Isopropyl Alcohol

   2.4 Rinse in Isopropyl Alcohol

   2.5 Dry

   2.6 Store in clean, dry, dustfree, covered containers

3. Die Attach

   3.1 Preheat package on a hotplate to 150°C ± 10°C

   3.2 Transfer prewarmed package to heat column set at 425°C and flushed with Dry Nitrogen

   3.3 Scrub in dice (ultrasonic)

   3.4 Remove from heat column

   3.5 Store assembled substrate in a clean, dry container

4. Wire Bonds

   4.1 Place package on heat column set at 200°C

   4.2 Thermocompression wire bond devices to substrate

   4.3 Remove package from heat column

   4.4 Store in a clean, dry, container

5. Cover Weld

   5.1 Mount package on welding fixture

   5.2 Align the cover and package and clamp in place

   5.3 Advance welding fixture until it engages drive worm

   5.4 Adjust to obtain the following welding parameters:

| | |
|---|---|
| Atmosphere | $N_2$ with less than 400 PPM moisture |
| Peak-to-peak current | 900 amperes |
| Pulse duration | 10 milliseconds |
| Pulse repetition period | 60 milliseconds |
| Sensitivity circuit | Peak |
| Feed rate | 40 |

   5.5 When the welding fixture returns to the starting position, unload package

   5.6 Store in a clean dry container

## 4.4 Covers for Package Types 1 and 2

The metal (F-15 alloy) covers for package Types 1 and 2 are fabricated by brazing together a stamped 0.005-inch thick lid and 0.007-inch thick, 1-inch diameter reinforcement disc shown in Figures 13 and 14. Prior to brazing, the covers and discs are tumbled to remove all stamping burrs from the edges including the welding portion of the flange. The parts are then nickel plated and sintered prior to brazing to prevent the intergranular corrosion of the silver in the braze and the nickel-iron (F-15 alloy). Following brazing the cover assembly is then gold plated to increase the corrosion resistance.

The cover design provides a nominal 0.050-inch internal height clearance above the circuit metallization and it is structurally strong to prevent deflection and shorting of the circuit components. This cover design is well suited for parallel seam welding since the increased electrical conductivity in the area of the brazed reinforcement disc reduced the power loss between the welding electrodes. Fabrication of a one piece 0.015-inch thick metal cover drawn and coined to a 0.005-inch thick welding flange is considered by the suppliers contacted to be beyond-the-state-of-the-art.

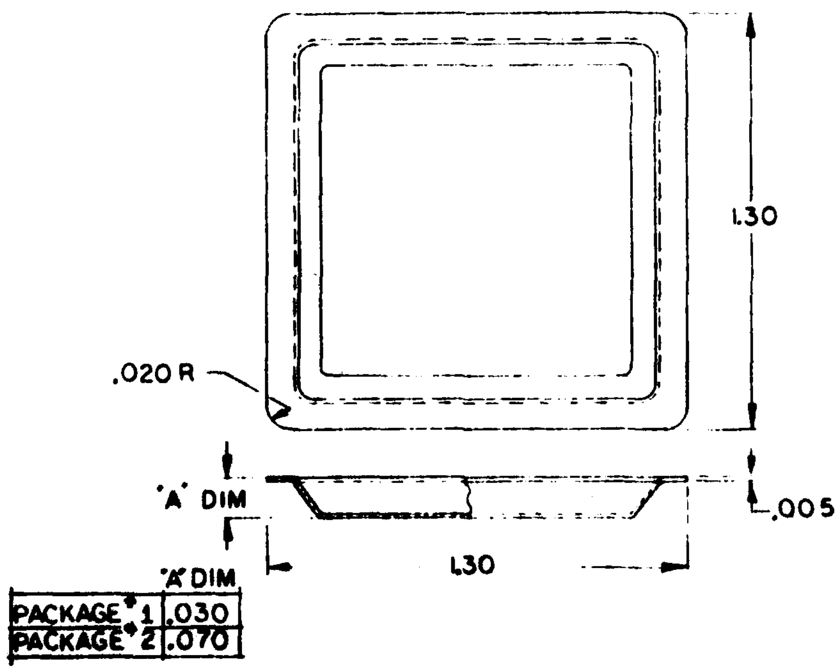


**Figure 13 - Coined Cover**

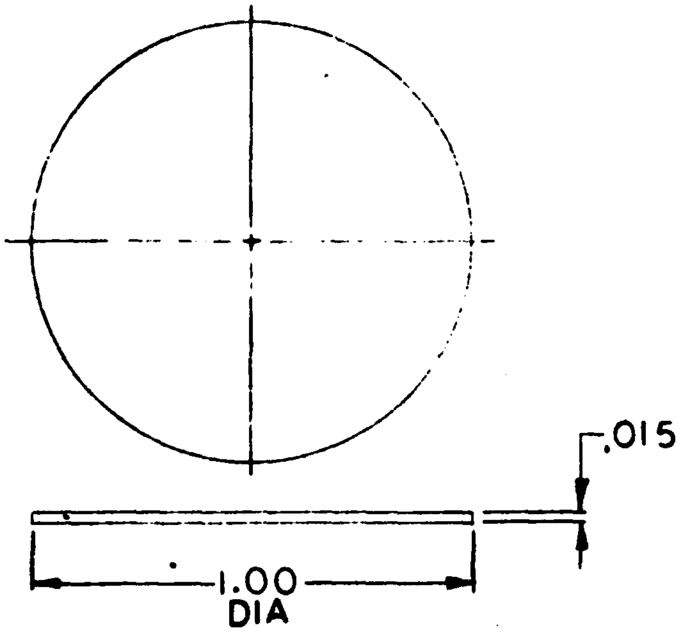


Figure 14 - Strengthening Disk

The cover assembly is fabricated using the processes shown in Figure 15 and described in subsequent pages.

1. Material

   1.1 Covers - F-15 alloy
   (Drawing Number HJF0120701P1 or HJF0120701P2)

   1.2 Disc - F-15 alloy
   (Drawing Number HJF0120703)

   1.3 Braze preform - 72-percent Silver - 28-percent Copper, VTG grade, 1/2-inch diameter - 0.002-inch-thick or equivalent

2. Deburr (covers and discs)

   2.1 Tumble the covers and discs for two hours in a wet media or until all burrs are removed to remove uneven finish along the edges.

3. Clean - Covers and Discs

   3.1 Degrease the covers and discs in trichloroethylene

   3.2 Soak 10 minutes in hot (75°C to 90°C) alkaline solution of Trisodium Phosphate - 2 oz/gal

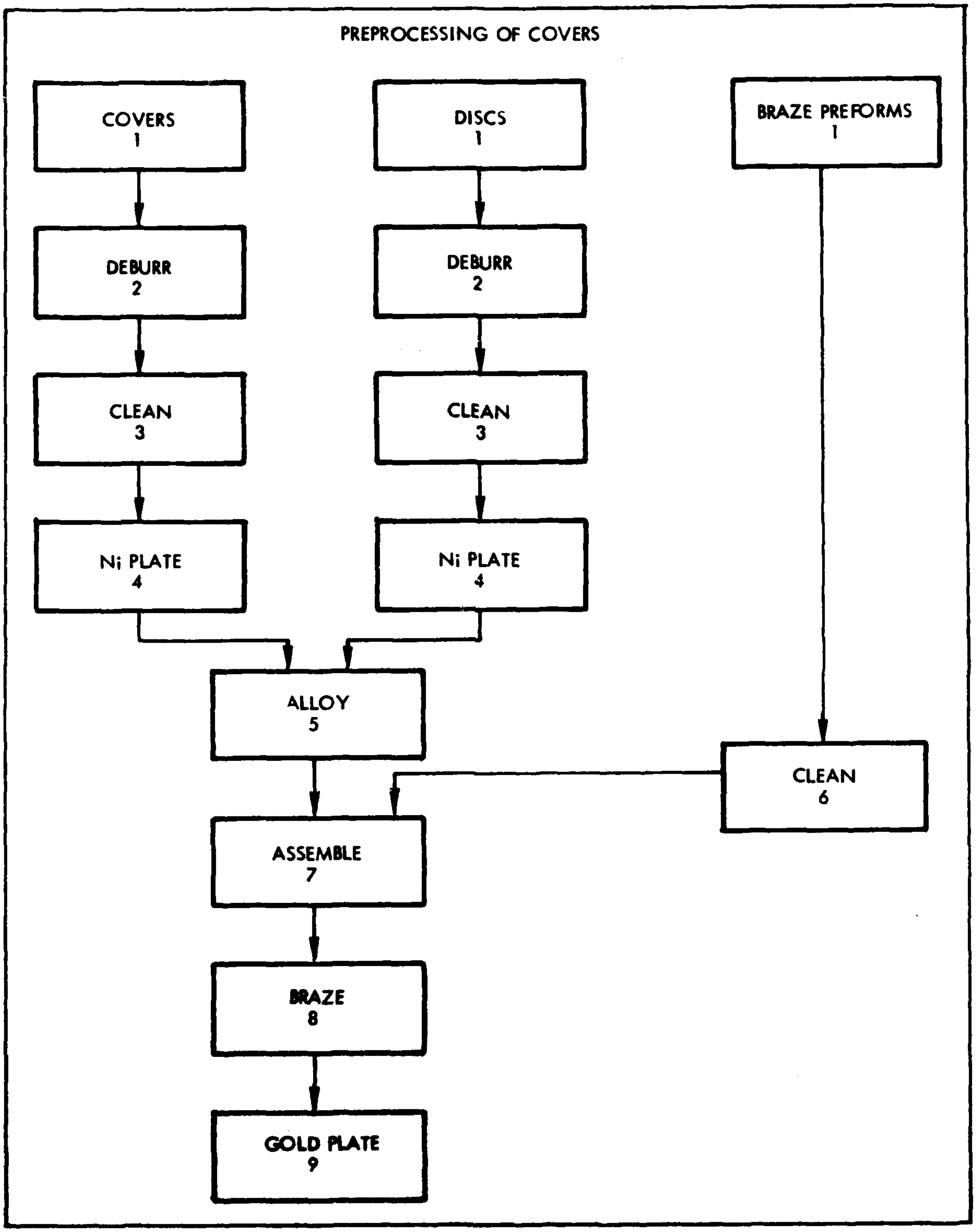


**Figure 15 - Cover Fabrication Sequence**

3. 3 Immerse in a hot acid bath - 50-percent HCl and FeCl (1 oz/ gal) for 30 seconds

3. 4 Rinse in hot water (75°C to 90°C)

3. 5 Neutralizer rinse (lime water)

3. 6 Cold water rinse (DI water)

3. 7 Isopropyl Alcohol rinse

3. 8 Isopropyl Alcohol rinse

3. 9 Dry and store in clean, dry, dustfree covered containers

4. Nickel Plate

4. 1 Activate surfaces to be plated

4. 2 Electroplate 100 millionths (minimum) of nickel using a sulphamate nickel type solution

4. 3 Rinse in water

4. 4 Dry

4. 5 Store in clean dry dustfree covered container

5. Alloy

5. 1 Load clean parts into furnace trays

5. 2 Load trays on the furnace conveyor belt set to bring parts to 1100°C for five minutes in reducing atmosphere

5. 3 Store in clean, dry, dustfree, covered containers

6. Clean Braze Preforms

6. 1 Rinse braze preforms sequentially in the following solutions:

6. 1. 1 Trichloroethylene 5-minute Soak

6. 1. 2 Acetone Rinse

6. 1. 3 Isopropyl Alcohol Rinse

6. 1. 4 Isopropyl Alcohol Rinse

6. 1. 5 Dry

6. 2 Store in a clean dry container

7. Cover Assembly

7. 1 Center the copper-silver eutectic braze preform in the bottom of the cover

7. 2 Place disc on top of braze preform

7. 3 Tack-weld the assembly together in the center

7. 4 Store assembled covers in a clean storage container

8. Braze

8.1 Load trays on belt conveyor furnace

8.2 Fire the cover assembly at 825°C ± 10°C for three minutes in a reducing atmosphere. The brazed cover should be less than 150°C when exiting the furnace.

8.3 Store completed part in the clean storage box

9. Gold Plate

9.1 Clean and activate surface of parts

9.2 Gold plate 100 millionths with 24 carat gold

9.3 Rinse in DI water

9.4 Dry

9.5 Store in clean, dry, dustfree, storage containers

## 4.5 Electron-Beam and Laser Braze Welding

Electron beam and laser welding methodologies were investigated. In the electron beam and laser technique, the approach evaluated was that of braze welding where the high energy electrons or photons are focused onto a silver/copper eutectic alloy frame 0.002 inch thick sandwiched between the cover flange and sealing frame on the package. In the braze-weld approach, the sealing temperature required is less than that required in welding. The lower sealing temperature minimizes the amount of gold alloyed into the cover. Suitable braze-welds have been made by both the laser and electron beam process. Since no evidence of degradation or failure has been found in temperature cycling, thermal shock and vibration evaluation of sealed packages, it can be concluded that a high-energy localized heating source is practical for sealing large laminated-ceramic packages.

4.5.1 Electron Beam Welding

Localized melting of metal can be accomplished by focusing a beam of high-velocity electrons on a filler material such as silver/copper eutectic alloy sandwiched between the cover flange and the window frame of the package. A continuous braze joint is formed when the work piece is moved beneath the electron beam; formation of a hermetic seal thereby is readily accomplished without damaging or alloying the gold-plating on the iron-nickel-cobalt alloy parts. The attainment of a braze joint is possible by this method, and the danger of overheating the semiconductor integrated circuitry within the package is greatly reduced since the heat is localized. This is evidenced by noting the retention of the gold-plating which otherwise would alloy quickly into the base metal at 650°C. The quality of the braze joint is excellent, since it is formed at relatively low pressure within a vacuum chamber. Fairly complex and expensive fixturing equipment is required, however, to completely automate the process, and to hold the ceramic packages and covers for accurate positioning and movement beneath the electron beam.

Packages have been sealed using the following electron-beam welding technique:*

1) The package, braze preform (silver/copper eutectic), and cover are assembled and clamped.
2) The assembly is placed in the vacuum chamber, which then is evacuated ($1 \times 10^{-4}$ for minimum).
3) The piece is positioned by remote control so that the seam between the cover and the window frame is aligned beneath the beamspot. The spot diameter is approximately 0.015 inch in diameter.
4) With the beam on, the part is traversed through the beam at a speed of 45 inches per minute.
5) The chamber is opened, the assembly is turned to expose another edge, and the above sequence is repeated until all four sides are sealed.

---

* Electron-beam welder manufactured by Sciaky Brox. Co. Chicago, Ill. Model number VX 503042.

Although this is a slow procedure, the operation could be automated by designing appropriate remotely-controlled positioning fixtures. All of the packages sealed in this manner had hermetic seals exceeding $1 \times 10^{-8}$ cubic centimeters per second. Photomicrographs of the seals such as that shown in Figure 16 shows that sound metallurgical bonds were made between the cover and the package, and that the preform melted and wetted out on both sides, forming a continuous fillet without damaging the gold-plating on the adjacent areas of the joint.

### 4.5.2 Laser Welding

This technique involves pulses of high-energy photons directed to the edge of a silver/copper eutectic brazing preform sandwiched between the flange of the cover and the window frame of the package. Extremely fine focusing and consequently a small but extremely concentrated heat spot is possible by this method, as with the electron beam welder. Unlike the latter, spot melting is accomplished by means of pulses; therefore, there must be overlapping of these individual welds to form a continuous braze fillet. This method has advantages over the electron-beam method in that the overall cost of the equipment is considerably less and a vacuum is not required. The operation can be performed in a dry nitrogen or nitrogen/helium atmosphere, ensuring good backfilling of the packages. Selection of the most suitable and economical type of laser is important, since a number of types are available.

The first type evaluated in this program was a ruby laser. The pulse rate was slow, however, and the pulse duration was too short and intense to permit a uniform sealing operation. A more suitable system was found when the YAG laser* was tried. (Neodymium-doped Yttrium Aluminum Garnet.) This laser is capable of emitting long pulses, and preliminary braze seals indicate that the YAG is capable of producing metallurgically-sound continuous braze seals. The filler alloy melted and wetted to both the cover edge and the window frame of the package without excessively heating immediately adjacent areas so as to damage or alloy the gold-plating into the base metal. The cover edge can be the full thickness of the metal with-

* Manufactured by SPACERAYS Inc. Model No. 1010C2 (YAG-CRYSTAL) Burlington, Massachusetts

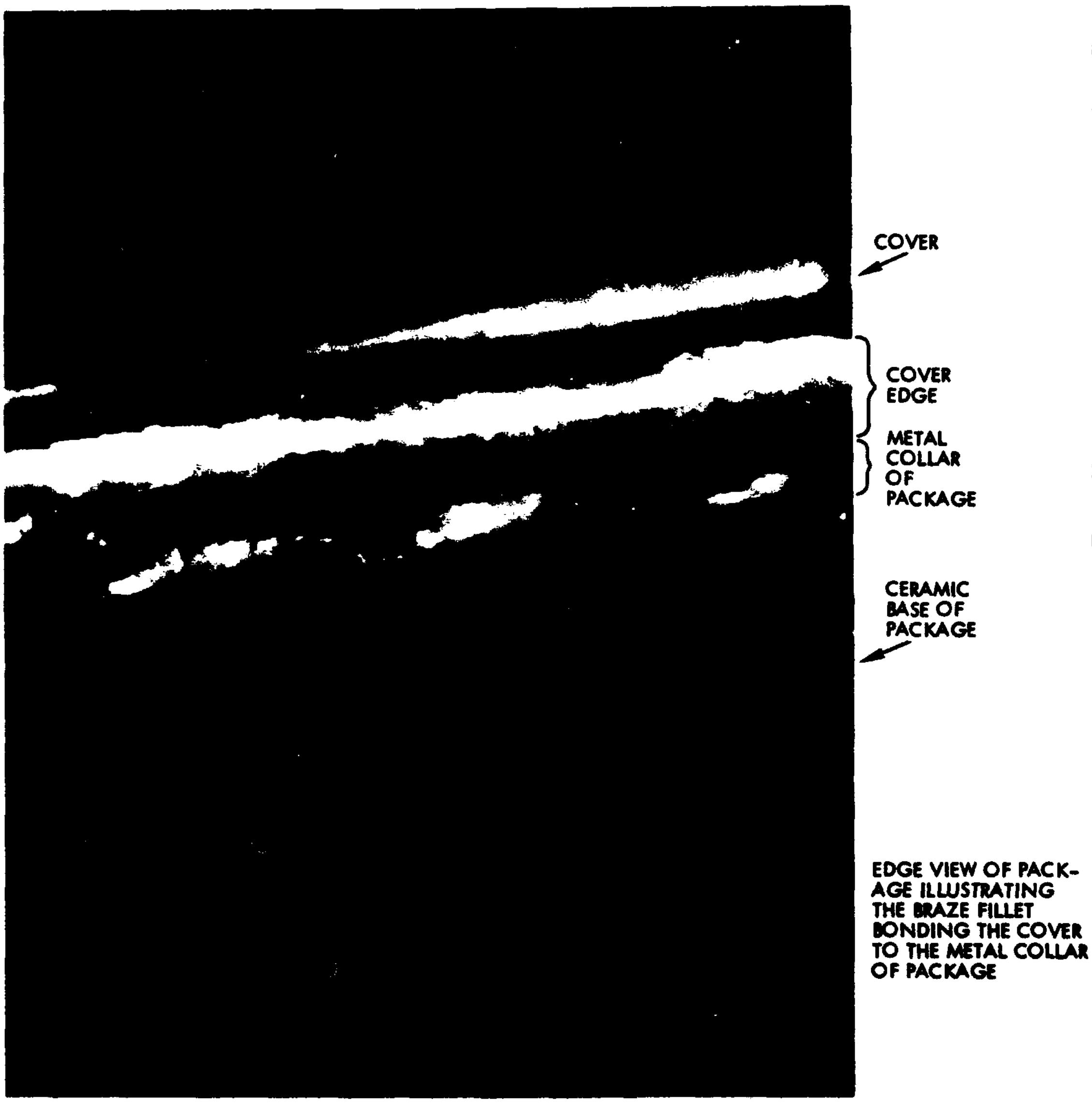


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**Figure 16 - Electron Beam Braze Seal (50X)**

out resorting to coining or other methods of making the thin flange as required with parallel-seam-welding techniques. Fixturing and jigging of the assembly is necessary, since only one side can be welded at a time. The traverse rate suitable for generating a continuous seam was found to be approximately 0.5 in./s. Figure 17 shows an enlarged photomicrograph of the YAG laser braze seal.

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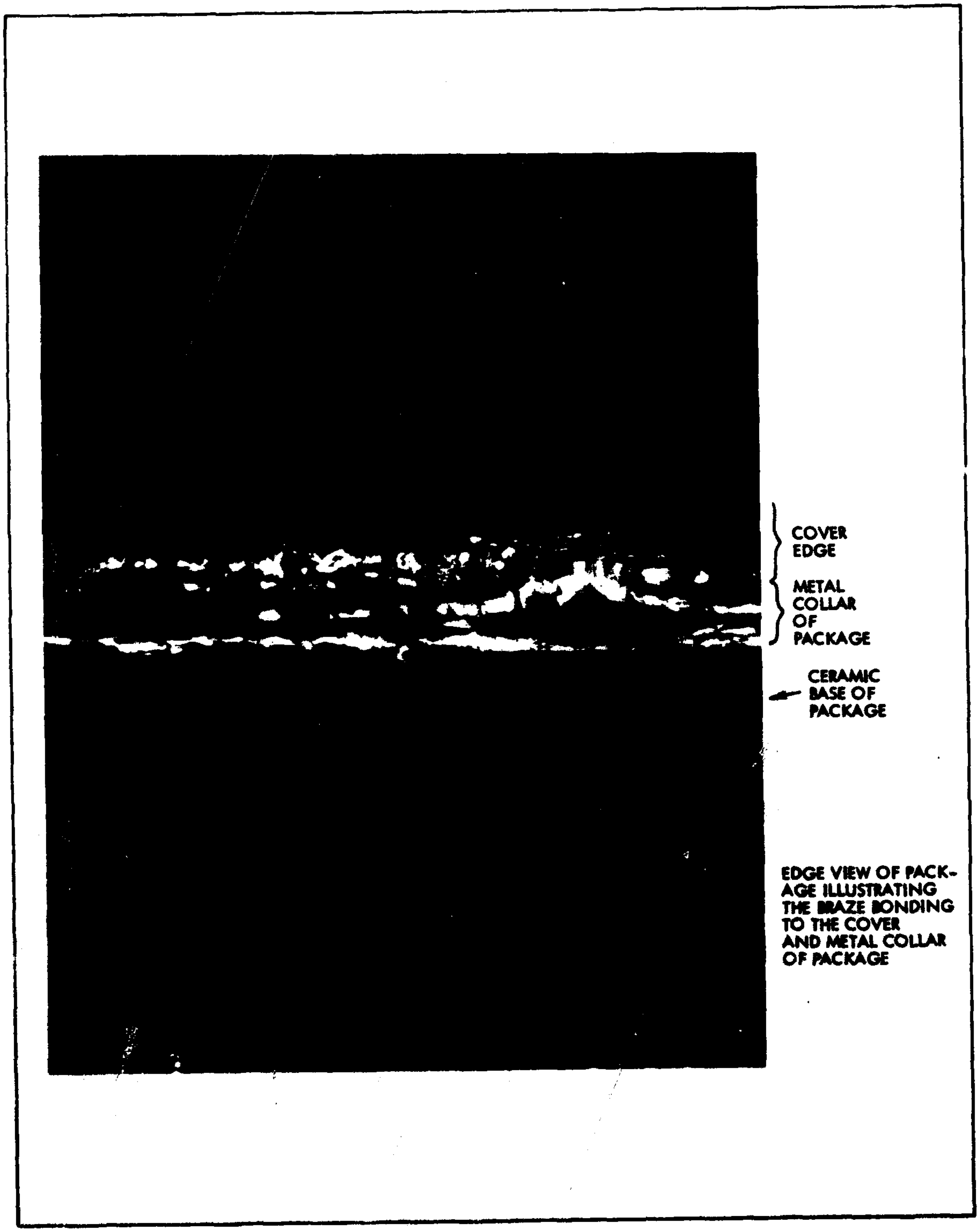


Figure 17 - Laser Braze Joint (40X)

## 4.6 Parallel Seam Welding

In this program, the maximum effort was aimed toward adapting the parallel-seam welder to the hermetic sealing of the packages. This technique has been successfully applied to the hermetic sealing of smaller packages, and preliminary results indicated that this technique also can be used for large packages. Sufficient statistics have been compiled in the industry to verify the basic reliability of this process, and its capability of producing high-yield rates with respect to hermetic sealing.

The parallel-seam welding equipment* shown in Figure 18 is contained in a dry box filled with nitrogen (or nitrogen plus ten-percent helium) having a moisture content of 40 ppm or less. This atmosphere provides an ideal ambient for the package and its contents. Figure 19 illustrates the operating principle of parallel seam welding.

### 4.6.1 Process Description

Parallel seam welding is accomplished by means of two 15 degree tapered roller electrodes which contact the edge of two opposing sides of the package cover. Heat is generated by current flowing through the high resistance of the small-area contacts between the two tapered electrodes and the lid flange thereby generating a series of overlapping welds as the rolls progress along the edge of the package. The welding power source supplies a controlled constant-current one kHz ac pulses which are adjustable in amplitude, duration and repetition rate. The rate for traversing the package under the roller electrodes can be adjusted to further optimize the bonding parameters. After the first two sides of the package have been traversed and welded the package is automatically rotated 90 degrees and the remaining two sides are welded on the return stroke.

In Figure 20 is shown a cross section view of a parallel seam weld seal. Figure 21 shows a brased-welded (silver/copper eutectic) seal between the cover and package sealing flange using the parallel seam welder. Since good hermetic seals were made using both the weld or braze-weld processes

* Manufactured by Solid State Equipment Corporation; Philadelphia, Penn.

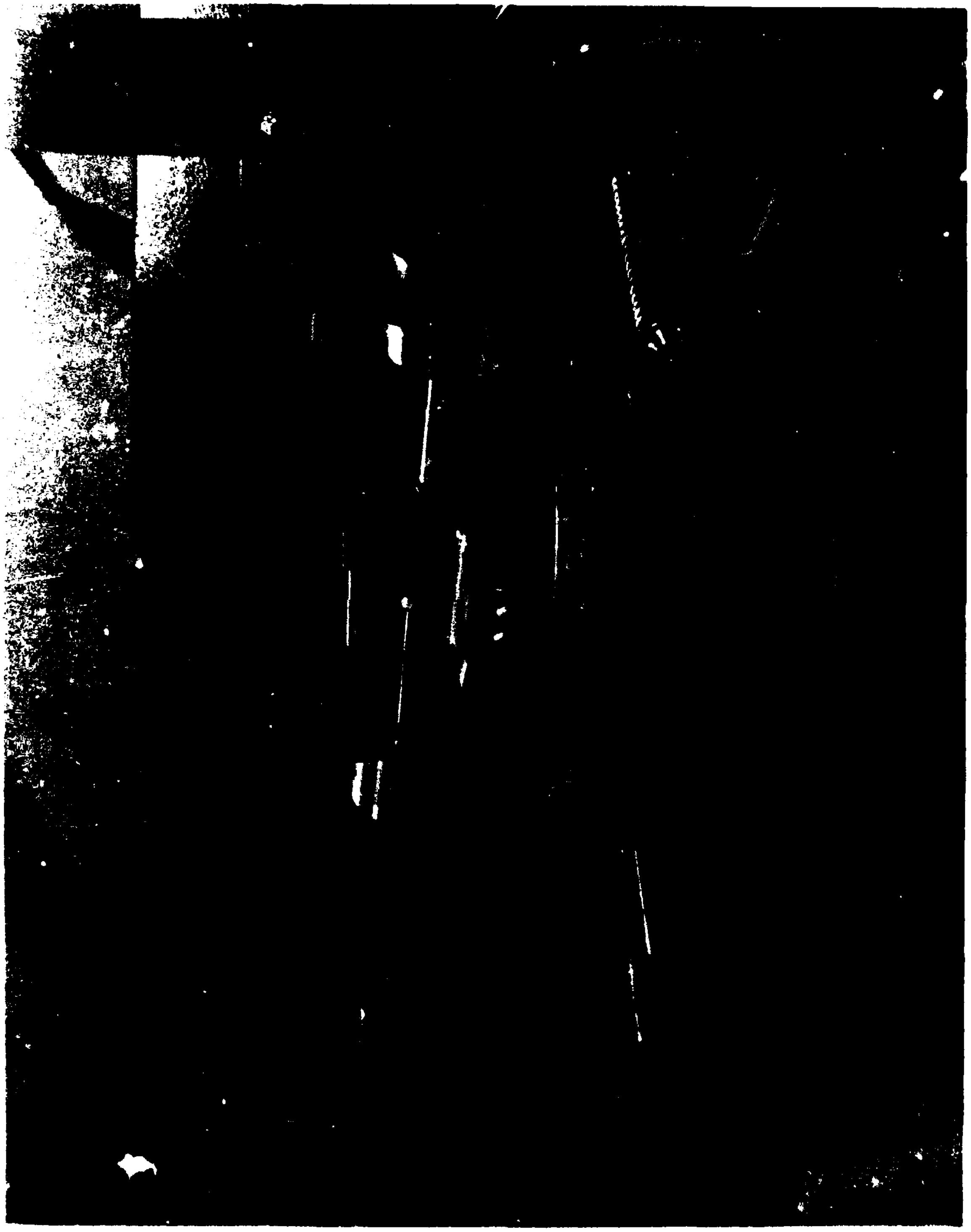

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Figure 18 - Parallel Seam

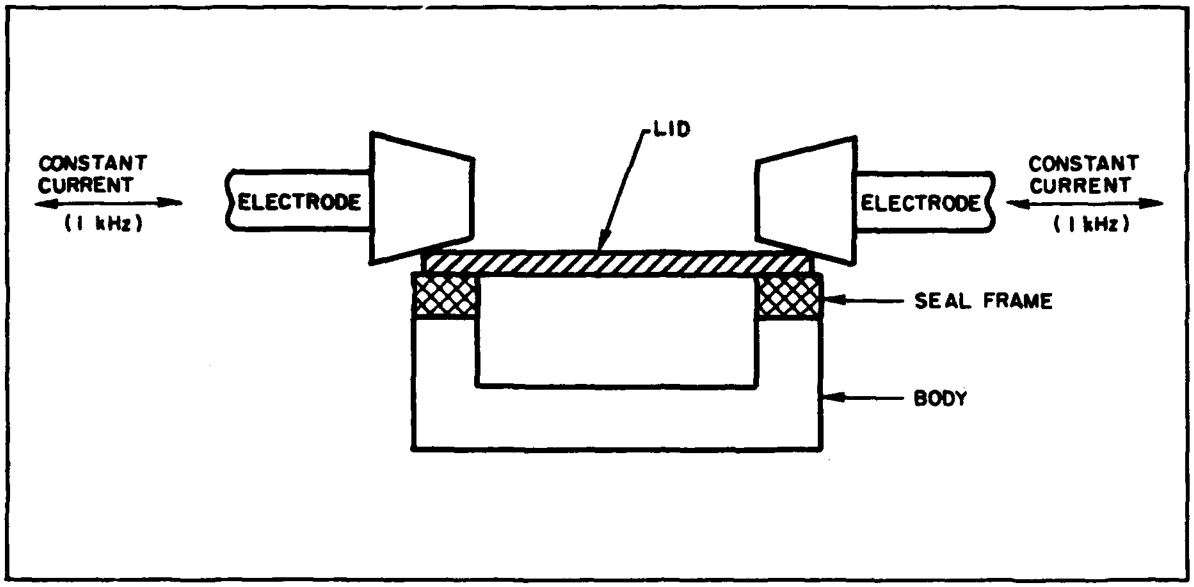


Figure 19 - Parallel Seam Sealing Package Cross Section


**Figure 20 - Parallel Seam Weld (130X)**

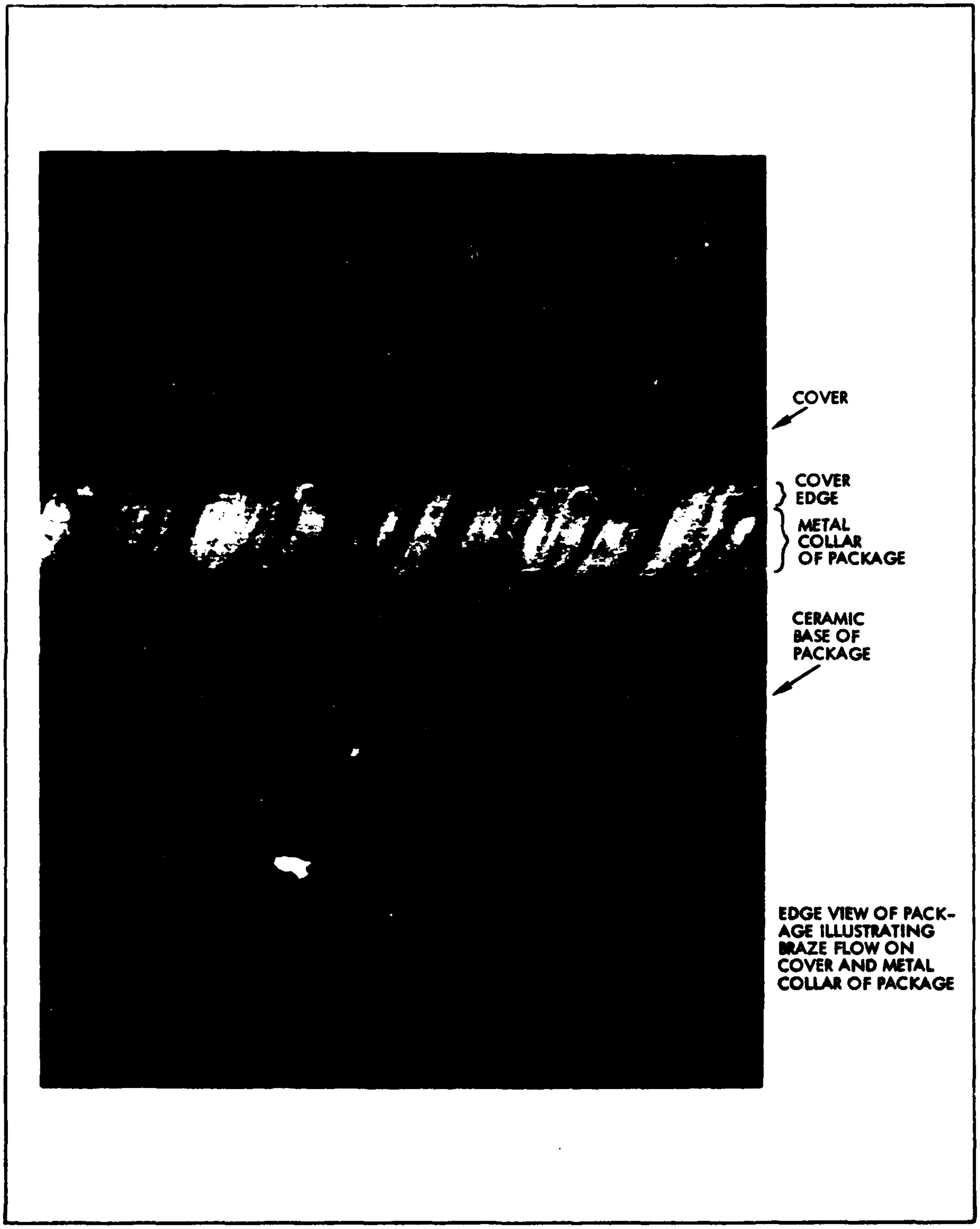


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**Figure 21 - Parallel-Seam Braze Weld (50X)**

the braze-weld method was not continued because of the added cost required of the braze preform and increased assembly complexity.

### 4.6.2 Welding Study

The major problems encountered in the parallel-seam welding were caused by power supply difficulties and arcing between the welding electrode and metal lid. During the period of this study the power supply required frequent repairs and was modified twice by the manufacturer to incorporate improved current limiting and high impedance sensing circuitry in an attempt to eliminate arc during the make and break contact of the welding electrode to the package lid. These modifications reduced but they did not eliminate the arcing problem - the major mode for sealing failures. The increased arcing problems encountered in sealing large packages, as compared to that reported in sealing flat packs, are accented by the higher power requirements for welding (3X). In view of the above results and following discussions with the equipment and package suppliers the following lid, package, and equipment modifications are recommended:

1) Increase the corner radius on the package sealing frame to 0.030 inch and the lid to 0.040 inch. This change will reduce the response time required in the high impedance sensing circuitry.
2) Reduce the gold plating thickness - Lower welding power can be used.
3) Replace the aluminum holding fixture in the welder with a stainless steel fixture. This modification will decrease the package heat sinking and allow the use of lower welding power.
4) Include a 5-degree angle on the lid sealing flange. This change will aid in contacting of the metal lid and package along the sealing area.

## 4.7 Cost Analysis

Selection of the multilayer ceramic package base with the parallel-seam welded cover achieves the program objectives for low cost, high volume production capability hybrid circuit packages. The manufacturer projected cost for the multilayer ceramic package base of either package Type 1 or 2 to be approximately $5.00 each in high volume production. Comparable 40-lead metal packages with glass eyelet lead feedthroughs or the glass-ceramic sealed packages currently in high volume production cost between $15.00 to $25.00 each. The gold plated laminated coined cover with the strengthening disc cost approximately $1.00 each for 100 microinch gold thickness. The 5-1/4 inch periphery of the developed packages can be parallel-seam welded at a rate of 30 pieces per hour.

The laser system has advantages of a high scanning or welding rate of up to 0.5-inch per second as compared to 0.2 inch per second for the parallel-seam welder. Practical utilization of this higher sealing rate of the laser systems with appropriate interlocking safety controls, weld monitor, drive and handling mechanisms presently requires a custom built system.

The parallel-seam welding system has advantages of lower equipment, operating and maintenance cost than does a comparable laser welding and electron beam welding systems. In addition, parallel-seam welding techniques for sealing SIC flat packs have been qualified for high reliability system applications in the industry and are being widely used.

## 4.8 Test Evaluation

The test sequence was performed following the plan shown in Figure 8 using the two package groups:

1) Packages subjected to high temperature storage and temperature cycling (150 units - mechanical packages).
2) Packages subjected to the qualification tests for delivery at the completion of the program (160 units - electrically good packages).

A production run was made of 310 sealed units of each package type. The following sealing yield was realized.

| | Mechanical Packages | Electrical Packages |
|---|---|---|
| Package Type I | 75 percent | 66 percent |
| Package Type II | 87 percent | 70 percent |

Most of the sealing rejects had leaks in the corner of the package caused by arcing between the sealing electrode and package cover on either the initiation or termination of the electrical contact. This condition resulted in either arc errosion of the corner or pitting of the roller electrode which in turn would cause an arc and metal errosion on contacting the package flange.

### 4.8.1 Seal Tests

The Seal Test was performed per MIL-STD-883, Condition A and C (Step 1). Fine leak testing of these units did present several technical problems including surface retention of the helium and surface condition change after environmental testing. To minimize these problems, the packages were prebaked a minimum at 100°C for one hour prior to testing. All data was taken using the measured leak rate with the equipment calibration prior to use and checked every hour during usage.

### 4.8.2 Temperature Cycle

The packages subjected to the temperature cycling test contained one eutectic-bonded inactive semiconductor chip and series of eight internal thermocompression wire bonds to provide continuity between eight external leads. Results of the temperature cycle tests are shown in Table 1.

### 4.8.3 High Temperature Storage

The test packages for the high temperature storage test contained one eutectic-bonded inactive semiconductor chip and a series of eight internal thermocompression wire bonds to provide continuity between the eight external leads.

TABLE 1

TEMPERATURE CYCLE TESTS

| | Package I | Package II |
|---|---|---|
| Hermetic Good Packages* | 50 | 42 |
| Hermetic Failures** | 44 | 2 |
| Electrical Failures | 0 | 0 |

*Leak rate < $1 \times 10^{-8}$ cc/s

**Leak rate > $1 \times 10^{-8}$ cc/s

Four subgroups of 25 test packages of each type were subjected to respective storage temperatures of 200°C, 300°C, 350°C, and 400°C. The test extended 500 hours, with five samples from each subgroup removed at 200 hours, five samples removed at 300 hours, five samples removed at 400 hours, and the final 10 samples in each subgroup removed after 500 hours. The test results are shown in Table 2.

The test packages used in the 350 degree temperature storage test included those previously used for the 200°C temperature storage test. The original 25 test units were destroyed in test due to an equipment breakdown.

TABLE 2

HIGH TEMPERATURE STORAGE TESTS

| Storage Temperature | Test Hours | Package Type I | | | Package Type II | | |
|---|---|---|---|---|---|---|---|
| | | No. of Units in Test[1] | Hermetic Failures[2] | Electrical Failures[3] | No. of Units in Test[1] | Hermetic Failures[2] | Electrical Failures[3] |
| 200°C | 200 | 5 | 1[4] | 0 | 5 | 0 | 0 |
| | 300 | 5 | 0 | 0 | 5 | 0 | 0 |
| | 400 | 3 | 0 | 0 | 5 | 0 | 0 |
| | 500 | 9 | 0 | 0 | 7 | 0 | 0 |
| 300°C | 200 | 4 | 0 | 0 | 5 | 0 | 0 |
| | 300 | 5 | 0 | 0 | 4 | 0 | 0 |
| | 400 | 2 | 0 | 0 | 4 | 1 | 1 |
| | 500 | 7 | 0 | 0 | 8 | 2 | 1 |
| 350°C | 200 | 5 | 0 | 0 | 5 | 1[4] | 0 |
| | 300 | 5 | 0 | 0 | 4 | 0 | 0 |
| | 400 | 3 | 0 | 0 | 5 | 0 | 0 |
| | 500 | 10 | 0 | 0 | 8 | 0 | 0 |
| 400°C | 200 | 0 | 0 | 1 | 1 | 0 | 0 |
| | 300 | 0 | 0 | 1 | 5 | 2 | 0 |
| | 400 | 0 | 0 | 2 | 3 | 0 | 2 |
| | 500 | 0 | 0 | 1 | 5 | 3 | 2 |

[1] Leak rate < $1 \times 10^{-8}$ cc/s.

[2] Leak rate > $1 \times 10^{-8}$ cc/s.

[3] Continuity failure.

[4] Substrate fractured in handling.

#### 4.8.4 Qualification Tests

The qualification test samples contain the following active devices: two digital SIC's type RG-230 Quad 2 input OR expander gate, one analog type RM 709 operational amplifier and two diodes type 1N914. These devices were chosen for lead accessibility to enable direct testing of the critical parameters.

Electrical measurements were made before and after qualification testing using a Fairchild Model 5000D computer controlled test set. Test measurements include:

1) RG230 - Logic on-off states
2) RM709 - Input offset voltage, output voltage swing, large signal gain
3) 1N914 - Forward to backward current voltage ratio to vendor's specifications

Test results are shown in Tables 3 and 4 for package Types I and II, respectively. Analysis of the test data does not show a correlation between electrical test results and hermeticity values for packages other than those having gross leaks.

Both package Types I and II failed the salt spray test due to corrosion pits in the plateau area of the cover and on the package leads. The weld area on the lid periphery was not affected in this test. Initial test samples of packages and lids plated with 100 microinches of nickel and 100 microinches of gold passed the salt spray. The failure in the qualification units is attributed to an increased porosity of the gold plating.

TABLE 2

HIGH TEMPERATURE STORAGE TESTS

| Storage Temperature | Test Hours | Package Type I | | | Package Type II | | |
|---|---|---|---|---|---|---|---|
| | | No. of Units in Test[1] | Hermetic Failures[2] | Electrical Failures[3] | No. of Units in Test[1] | Hermetic Failures | Electrical Failures[3] |
| 200°C | 200 | 5 | 1[4] | 0 | 5 | 0 | 0 |
| | 300 | 5 | 0 | 0 | 5 | 0 | 0 |
| | 400 | 3 | 0 | 0 | 5 | 0 | 0 |
| | 500 | 9 | 0 | 0 | 7 | 0 | 0 |
| 300°C | 200 | 4 | 0 | 0 | 5 | 0 | 0 |
| | 300 | 5 | 0 | 0 | 4 | 0 | 0 |
| | 400 | 2 | 0 | 0 | 4 | 1 | 1 |
| | 500 | 7 | 0 | 0 | 8 | 2 | 1 |
| 350°C | 200 | 5 | 0 | 0 | 5 | 1[4] | 0 |
| | 300 | 5 | 0 | 0 | 4 | 0 | 0 |
| | 400 | 3 | 0 | 0 | 5 | 0 | 0 |
| | 500 | 10 | 0 | 0 | 8 | 0 | 0 |
| 400°C | 200 | 0 | 0 | 1 | 1 | 0 | 0 |
| | 300 | 0 | 0 | 1 | 5 | 2 | 0 |
| | 400 | 0 | 0 | 2 | 3 | 0 | 2 |
| | 500 | 0 | 0 | 1 | 5 | 3 | 2 |

[1] Leak rate $< 1 \times 10^{-8}$ cc/s.

[2] Leak rate $> 1 \times 10^{-8}$ cc/s.

[3] Continuity failure.

[4] Substrate fractured in handling.

### 4.8.4 Qualification Tests

The qualification test samples contain the following active devices: two digital SIC's type RG-230 Quad 2 input OR expander gate, one analog type RM 709 operational amplifier and two diodes type 1N914. These devices were chosen for lead accessibility to enable direct testing of the critical parameters.

Electrical measurements were made before and after qualification testing using a Fairchild Model 5000D computer controlled test set. Test measurements include:

1) RG230 - Logic on-off states
2) RM709 - Input offset voltage, output voltage swing, large signal gain
3) 1N914 - Forward to backward current voltage ratio to vendor's specifications

Test results are shown in Tables 3 and 4 for package Types I and II, respectively. Analysis of the test data does not show a correlation between electrical test results and hermeticity values for packages other than those having gross leaks.

Both package Types I and II failed the salt spray test due to corrosion pits in the plateau area of the cover and on the package leads. The weld area on the lid periphery was not affected in this test. Initial test samples of packages and lids plated with 100 microinches of nickel and 100 microinches of gold passed the salt spray. The failure in the qualification units is attributed to an increased porosity of the gold plating.

TABLE 3

PACKAGE TYPE I QUALIFICATION TESTS

| Control Group | Test Units | Thermal Shock 1011 Condition C | | Mechanical Shock 2002 Condition B | | Vibration 2007 Condition C | | Altitude 1001 Condition D | | Moisture 1004 | | Electrical[1] Failures in (P) units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P | F | P | F | P | F | P | F | P | F | |
| 1 | 30 | 29 | 1 | 28 | 1 | 24 | 4 | 24 | 0 | 24 | 0 | 0 |
| 2 | 30 | | | 30 | 0 | 29 | 1 | 29 | 0 | 29 | 0 | 2 |
| 3 | 32 | | | | | 31 | 1 | 30 | 1 | 30 | 0 | 3 |
| 4 | 17 | | | | | | | 17 | 0 | 17 | 0 | 1 |
| 5 | 16 | | | | | | | | | 16 | 0 | 2 |

[1]Does not include salt spray and solderability packages.

P - Passed < $1 \times 10^{-8}$ cc/s leak rate.

F - Failed > $1 \times 10^{-8}$ cc/s helium leak rate.

Salt Spray - Test method 1009-C; 22 units tested from control groups 1 to 5 - 22 units failed test.

Solderability - Test method 2003; 22 units tested from control groups 1 to 5 - 22 units passed test.

## TABLE 4

## PACKAGE TYPE II QUALIFICATION TESTS

| | | Thermal Shock 1011 Condition C | | Mechanical Shock 2002 Condition B | | Vibration 2007 Condition C | | Altitude 1001 Condition D | | Moisture 1004 | | Electrical[1] Failure in (P) units | Salt Spray 1009-C (22 units) | | Solderability 2003 (22 units) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control Group (32 units) | Test Units | P | F | P | F | P | F | P | F | P | F | | P | F | P | F |
| 1 | 32 | 31 | 1 | 31 | 0 | 31 | 0 | 31 | 0 | 31 | 0 | 1 | 0 | 22 | 22 | 0 |
| 2 | 29 | | | 29 | 0 | 29 | 0 | 29 | 0 | 29 | 0 | 0 | 10 | 8 | 0 | 0 |
| 3 | 26 | | | | | 26 | 0 | 26 | 0 | 26 | 0 | 0 | | | | |
| 4 | 23 | | | | | | | 23 | 2 | 21 | 0 | 0 | | | | |
| 5 | 3 | | | | | | | | | 3 | 0 | 1 | | | | |

[1] Does not include salt spray solderability test units.

P - Passed < $1 \times 10^{-8}$ cc/s

F - Fail > $1 \times 10^{-8}$ cc/s.

# 5. CONCLUSION

The multilayer ceramic base and parallel-seam welded packaging concept developed in this program has been shown to provide a low cost, hermetic and reliable enclosure for hybrid microassemblies, with the exception of two problem areas. First, the anticipated high sealing yield was not realized due to corner "blow-out" or erosion of the metal lid during roll-on or roll-off of the weld electrodes onto the package. Second, there was insufficient corrosion resistance of the metal lid, seal frame, and lead frame.

From the results and experience obtained in this program, it is felt that the two problem areas can be eliminated with the following design and process modifications.

1) Parallel-seam weld sealing equipment - Improve the control for turn-on and turn-off of the welding current.
2) Package design - Change the lead frame and seal frame material and/or plating for improved corrosion resistance.
3) Lid design - Change the lid material and/or plating for improved corrosion resistance. The lid should be redesigned to optimize the welding properties.

B

# PHASE II

(Work under Contract Extension)

# 6. PROGRAM OBJECTIVE

The objective of this program is to increase the sealing yield and corrosion resistance of parallel-seam welded multilayer ceramic packages above that obtained in Phase I (see Sections 1 through 5 of this document).

Techniques, materials and design for the package and lid will be developed to reduce corner arcing between the welding electrodes and the package for the parallel seam welding process and to increase the corrosion resistance of the package seal frame, leads and lid.

# 7. APPROACH

The approach undertaken in this program is a continuation of the parallel seam weld sealing of a metal lid to a multilayer ceramic package which contains buried layer metallizations for electrical interconnections beneath the sealed cover. From the results of the previous study, it is apparent that higher sealing yields - elimination of corners arcing between the weld electrode and package - and increased corrosion resistance can be obtained with selected design, material, and process changes in the package, lid, leads, and parallel seam welder. The separable substrate type package was selected for this study.

The following material design and process changes will be evaluated.

## 7.1 Metallurgy

The nickel and gold plated F-15 alloy package leads, seal frame and lid failed the MIL-STD-883 Method 1009 Condition A and C Corrosion Resistance Tests. The approach taken in this program to increase the corrosion resistance is to evaluate of various metallurgy systems including gold- and nickel-plated F-15 alloy, nickel-plated F-15 alloy and gold-plated copper-nickel alloys.

## 7.2 Package Design

The separable substrate package is selected for this study because of its general applicability for packaging hybrid circuits in the industry. The design of the separable substrate Type I package used in the previous study (see Sections 1 through 5 of this document), will be changed to optimize the parallel seam welding parameters and permit higher sealing yield. Major design considerations include:

1) Increase thickness of the ceramic base from 0.075 inch to 0.105 inch
2) Increase corner radius on the seal frame
3) Elimination of gold-plating on the seal frame
4) Use of copper-nickel alloy No. 725[1] lead frame (see Table 5)

## 7.3 Lid Design

A flat self-locating flanged lid designed to fit and be aligned to the separable substrate package will be evaluated. The flange thickness will be selected to provide good welding characteristics.

## 7.4 Parallel-Seam Welding Equipment

The parallel-seam welder will be modified to eliminate the electrode-to-package arcing previously encountered. Equipment modifications will be based on analytic studies of electrode contact.

## 7.5 Test

Two hundred packages incorporating the new designs will be sealed and evaluated for hermeticity per MIL-STD-883 Method 1014, Conditions A and C. Twenty-two of these sealed packages will be tested for corrosion resistance per MIL-STD-883 Method 1009, Condition A per requirements of the program. An additional 22 sealed packages will be tested for corrosion resistance per Method 1009, Condition C for test information and evaluation.

---

[1] Manufactured by Anaconda American Brass Company, Waterbury, Connecticut.

# 8. RESULTS

## 8.1 Package Design and Fabrication

The 40-lead, separable substrate, multilayer ceramic package was redesigned and manufactured by Metalized Ceramics Corporation, Providence, Rhode Island.

## 8.2 Lid Design and Fabrication

A flat, self-locating F-15 alloy lid was designed for the package. The lids were supplied by Solid State Equipment Corporation, Ft. Washington, Pa., and were plated by Fidelity Electronic Plating, Canton, Mass.

## 8.3 Parallel Seam Sealing Engineering

The parallel seam sealing process was improved by the new lid design, by the package redesign, and by sealing machine improvements.

## 8.4 Parallel Seam Sealing - Verification

Two-hundred packages were sealed using a Solid State Equipment Corporation Parallel Seam Sealer. A yield of 98.5 percent was obtained.

## 8.5 Test Evaluation

The packaging system developed, consisting of the multilayer ceramic package, nickel-plated F-15 alloy lid, and parallel-seam sealing, meets the program objectives - MIL-STD-883 hermeticity requirement (Method 1014 Conditions A and C) and corrosion resistance requirement (Method 1009 Condition A - 24 hours). The developed package passed the corrosion resistance per Method 1009 Condition C (96 hours) used in the additional evaluation.

# 9. DISCUSSION OF RESULTS

## 9.1 Package Design

The package design used in the second phase of the program is essentially a redesign of the Type 1 package, developed in the first phase. The redesign was deemed necessary, not because of deficiencies in the package, but rather to permit higher sealing yields.

### 9.1.1 Package Layers

The original Type 1 package was laminated from three ceramic layers, each 0.025 in. thick. To improve the sealing yield, it was decided that the drawn lids should be replaced by flat lids (see Subsection 9.2). To maintain adequate inside clearance, the package was redesigned to have four layers, each 0.035 in. thick. The structure is presented in Figure 22. It should be noted that no retooling of the ceramic layers was necessary; one of the layers was merely doubled up (the layer to which the lead frame is attached).

### 9.1.2 Seal Frame

A seal frame stamped from F-15 alloy is brazed to the top ceramic layer of the package (Figure 22). The design of this frame was found to be of paramount importance in achieving a weld-sealable package.

#### 9.1.2.1 Seal Frame Plating

Although the F-15 alloy seal frame is directly weldable, it must be protected against corrosion. A gold over nickel plating is commonly used in the microelectronic packaging industry, to protect F-15 type alloys; however, this approach was found unsatisfactory in the previous work (see Sections 1 through 5 of this document), and on evaluation of representative commercial parts. A sulfamate-nickel plating of 350 ± 50 microinches was found to pass the MIL-STD-883 Method 1009 Condition A Salt Spray

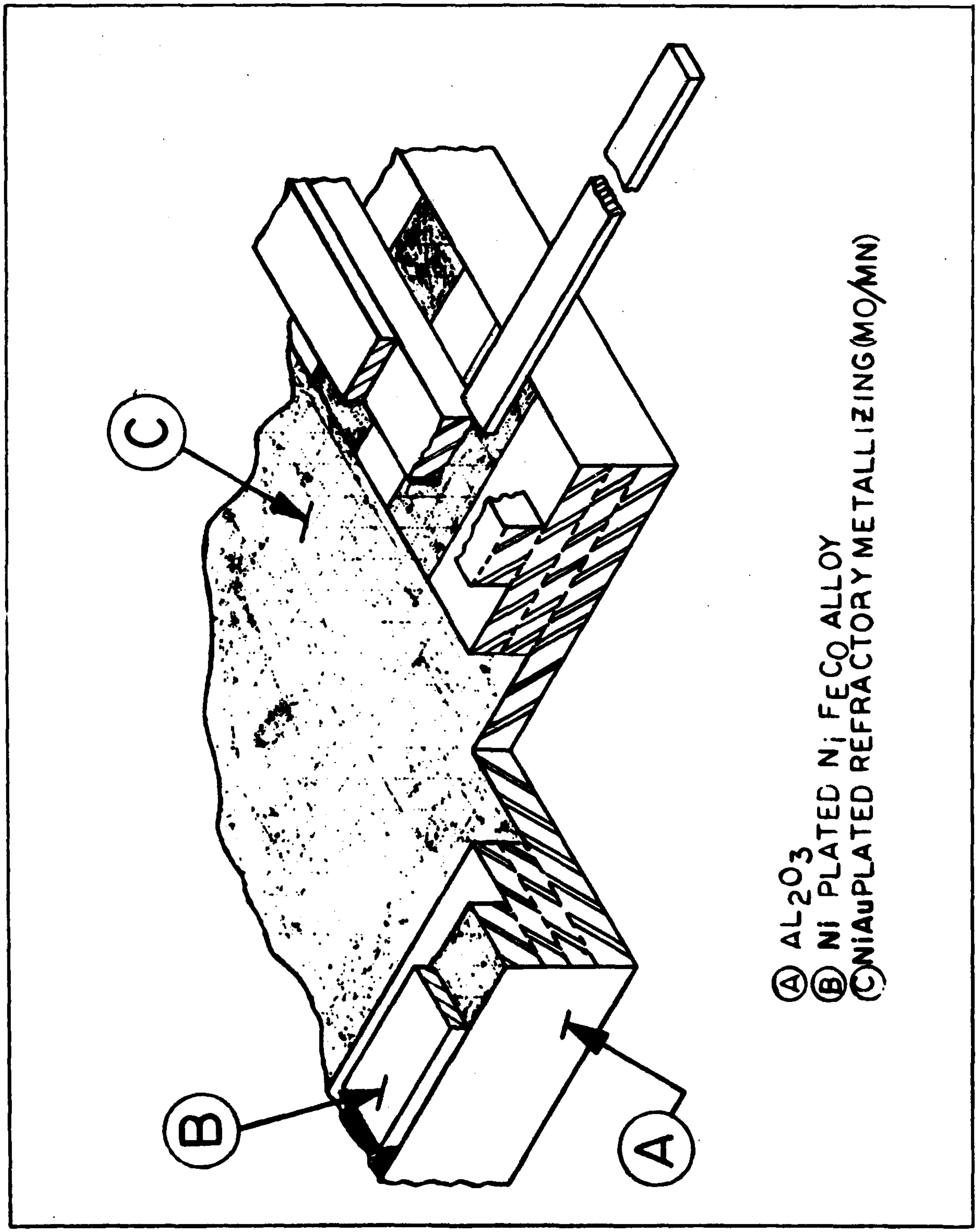



**Figure 22 - Redesigned Separable Substrate Package**

Corrosion Test. The gold-plating was eliminated because of the galvanic electromotive potential between nickel and gold, and the subsequent detrimental effect on corrosion resistance. This subject will be discussed in more detail in Subsection 9. 2. 3.

#### 9. 1. 2. 2 Package Seal Frame Dimensions

The thickness of the seal frame was increased to 0. 012 inch from the 0. 010 inch thickness used in the first phase of the program. The thicker frames stay flatter during the braze attachment to the package body.

The outside corner radius was increased from 0. 003 inch to 0. 061 inch, as part of the solution to the seam welding problem (see Subsection 9. 3).

The package seal frame edges were designed to be even with or slightly overhanging the top ceramic layer. This ensures mechanical clearance for the conical welding electrode. Clearance is especially important at the corners where the electrodes drop as they roll off the package. The sharp ceramic corners extending beyond the 0. 061 inch radius seal frame corner must be free of the braze fillet.

### 9. 1. 3 Lead Frame

The lead frame material was changed from F-15 alloy to Anaconda No. 725 Cupro-Nickel alloy. The specifications of this alloy are presented in Table 5.

The No. 725 cupro-nickel alloy, both unplated and plated with gold over nickel, passed the Salt-Spray Corrosion Resistance Test. This property is necessary, since the lead frame is nickel and gold-plated, when the internal bondings pad and package base are electroplated. The gold-plated lead frame is preferred for good solderability.

TABLE 5

COMPOSITION, FORMS AND PROPERTIES OF CUPRO-NICKEL
9 PERCENT 725

| | | | |
|---|---|---|---|
| Nominal Composition: | 88.78 Percent Copper<br>9.00 Percent Nickel | 2.00 Percent Tin<br>0.22 Percent Manganese | |
| Standard Forms: Sheet, strip, plate, wire, and tube | | | |
| Approximate Relative Machinability: 20 (based on Free Cutting Brass 360 arbitrarily rated at 100) | | | |
| Tensile Strength, psi: | Sheet and Strip | Wire | |
| (Hard) | 80,000 | 93,000 | |
| (Soft) | 52,000 | 52,000 | |
| Yield Strength @ 0.5% Extension Under Load psi: | | | |
| (Hard) | 76,000 | 25,000 | |
| (Soft) | 22,000 | 25,000 | |
| Elongation, % in 2 in. (except wire, which is % in 10 in.) | | | |
| (Hard) | 3 | | |
| (Soft) | 40 | | |
| Rockwell Hardness No: | | | |
| (Hard) | B90 | | |
| (Soft) | B42 | | |
| Melting Point (Liquidus): | 1129°C | (2064°F) | |
| Density: 0.321 lb/cu in. at 68°F | | | |
| Average Coefficient of Linear Thermal Expansion per °F (68-572°F): 0.0000092 | | | |
| Electrical Conductivity, % IACS @ 68°F (volumetric): | | | 11.0 (for soft, annealed metal; slightly lower in hard temper) |
| Thermal Conductivity, Btu/ft$^2$/°F @ 68°F: | | | 31 |
| Youngs Modulus of Elasticity, psi about 19,000,000 | | | |
| Data supplied and reproduced with permission by Anaconda American Brass Company, Research and Technical Center, Waterbury, Connecticut. | | | |

#### 9.1.4 Package Plating

Starting with the fired ceramic body, the following plating sequence is used.

1) Barrel plate nickel to a thickness of 50 microinches on the molymanganese metallization.
2) Attach seal frame and lead frame by brazing.
3) Electroplate nickel (300 to 400 microinches) on the seal frame, lead frame, and areas coated in Step 1.
4) Electroplate plate gold to a minimum thickness of 80 microinches on all areas except the seal frame. This plating permits wire bonding to the external pads, and enhances the low temperature braze attachment of a substrate to the package floor and solderability of the lead frame.

### 9.2 Lid Design

The self-locating flanged lid, shown in Figures 23 and 24, was designed for the separable substrate package.

This lid design was selected in order to optimize the welding parameters-lid package alignment and flange thickness.

#### 9.2.1 Lid Thickness

The F-15 alloy lid shown in Figures 23 and 24, was designed 0.015 inch thick for good rigidity on the large lid area, and with a thin flange 0.0055 inch thick for good parallel seam welding characteristics. This lid is distributed by Solid State Equipment Corporation, Fort Washington, Pennsylvania.

The lid is assembled to the package with the thick center area providing positioning and self-alignment to the seal frame. The flange thickness of 0.0055 in. (before plating) was determined experimentally to have good mechanical strength and welding properties after the 350 ± 50 microinch nickel plating.

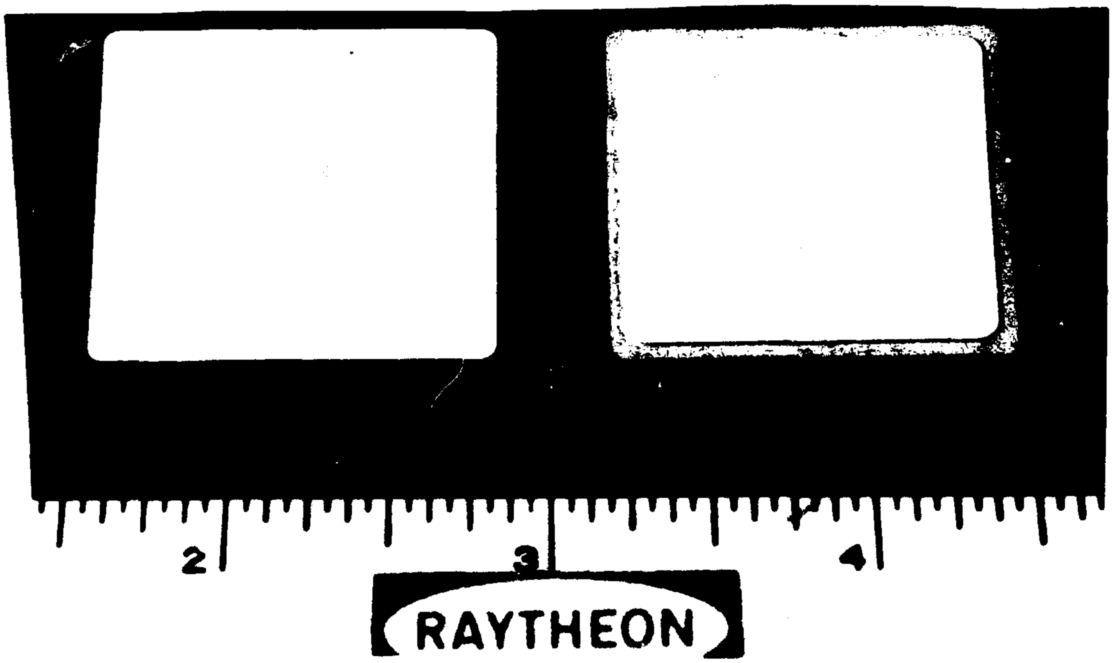



**Figure 23 - Redesigned F-15 Alloy Lid**

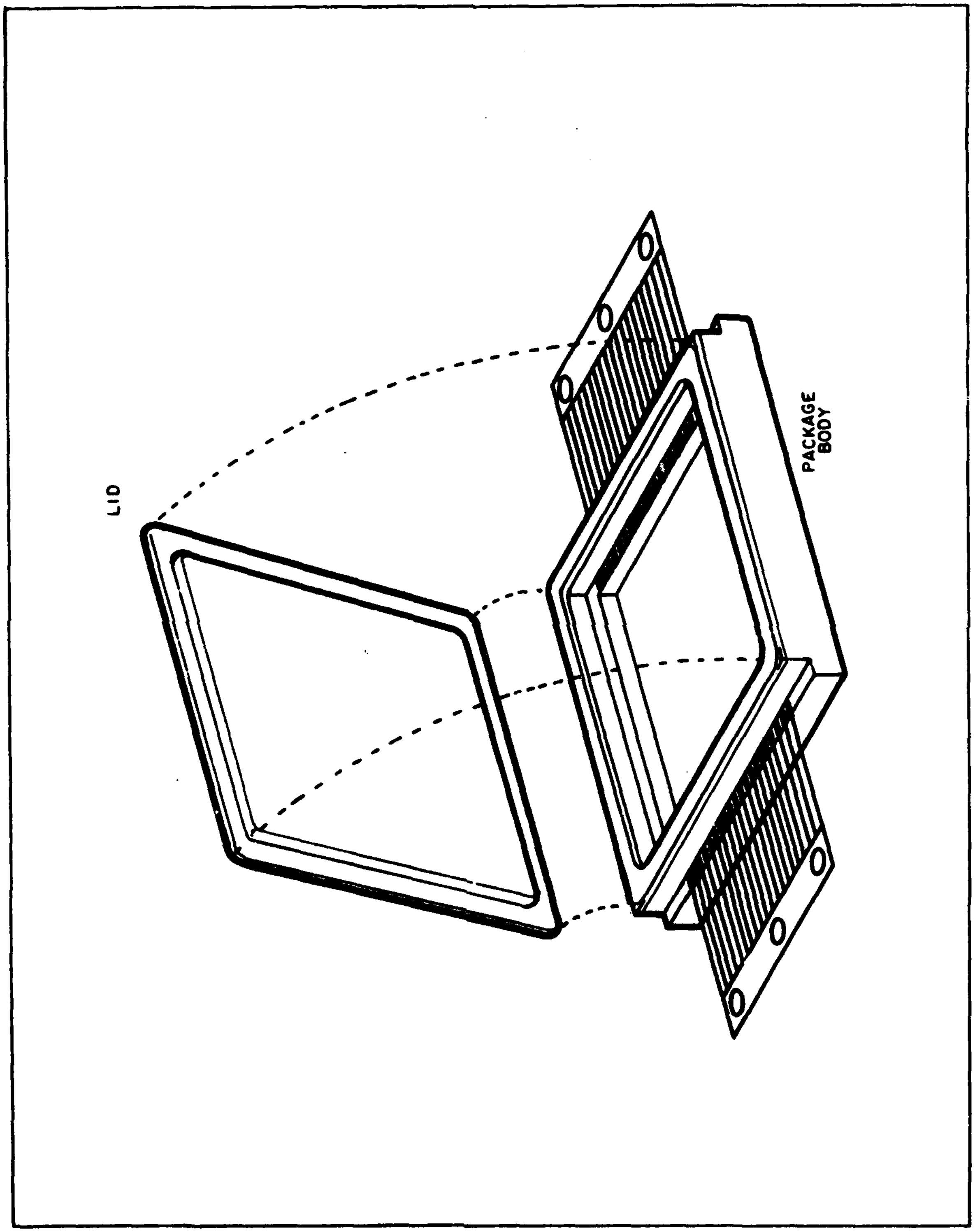



**Figure 24 - Lid Self-Location**

### 9.2.2 Lid Self-Location

The alignment of the lid relative to the seal frame was found to be critical to the parallel seam welding process. The lid edge was designed to self-locate 0.006 inch ± 0.003 inch inset from the outside edge of the seal frame without the aid of an alignment fixture.

To achieve alignment accuracies in the order of 0.003 inch, consideration must be made of the edge radius of the seal frame and of the inside corner radius of the lid at the step in thickness. The seal frame radius is the result of the stamping operation. The lid radius is a consequence of the etching procedure used in manufacture of the flanged lid. The combined effect of these radii must be compensated for in selecting the size of the lid "island".

The self-location feature of the lids was demonstrated during the sealing evaluation portion of the program, in that no alignment fixtures were required.

### 9.2.3 Lid Plating

Salt spray evaluation of F-15 alloy plated with nickel and gold, as found in commercial packages and lids, led to the conclusion that the degree of protection offered by this combination is variable and difficult to correlate with regard to plating thickness. Furthermore, it was demonstrated that the addition of gold plating to nickel plated F-15 alloy can be even more detrimental to salt spray performance. Figure 25 shows two plated/F-15 alloy lids that have been exposed to salt spray for 24 hours. Both lids were plated using a phosphorous type electroless nickel (150 microinches) with one of the lids receiving an application of gold plate (about 20 microinches). The lid with the gold flash exhibited corrosion after the MIL-STD-883 Method 1009 Condition A Salt Spray Test.

The increased corrosion from the gold is explained by the galvanic electromotive force between gold and nickel. Gold has an electromotive potential of -1.68V, whereas nickel, cobalt and iron (the elements in F-15 alloy) have potentials of +0.25, +0.28, and +0.44V, respectively.

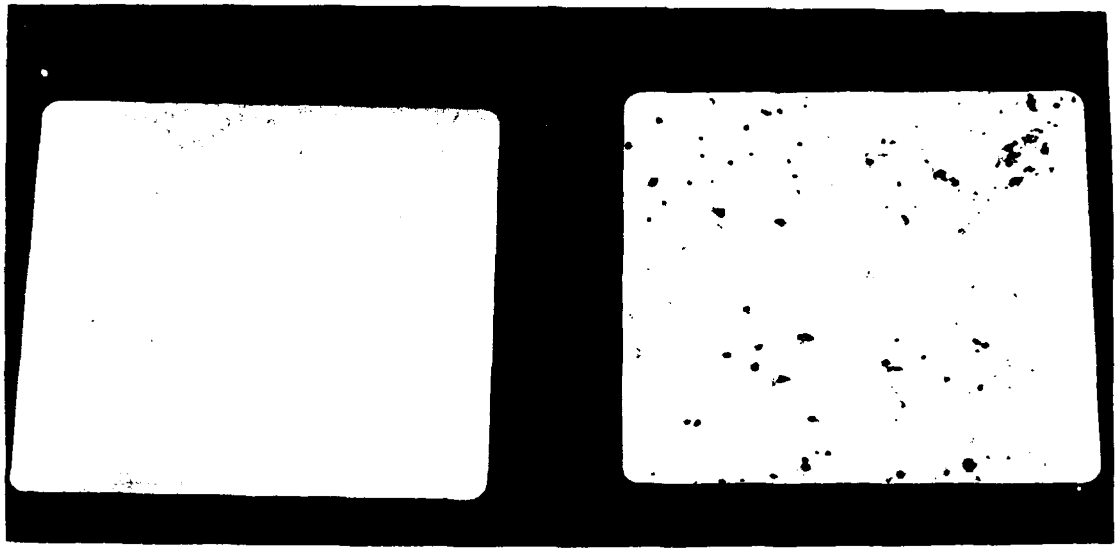


Figure 25 - Lids after 24 hours Salt Spray

It was experimentally determined that lids plated with 250 to 350 microinches of electroless nickel showed minimal evidence of corrosion after 96 hours exposure to salt spray, as may be seen in Figure 26.

## 9.3 Parallel Seam Sealing Engineering

A preliminary study of the seam sealing process determined that three conditions must be met to eliminate corner arcing:

1) Weld current must be turned on after mechanical contact of both electrodes to the package is achieved.
2) The weld current must be turned off before mechanical contact of either electrode is broken.
3) Electrode dwell, resulting from the roll-on or roll-off must be minimized to prevent excessive weld energy from being applied to the package corners.

Condition 1) above, is applicable to the roll-on of the electrodes; 2) to the roll-off; and 3) to both roll-on and roll-off.

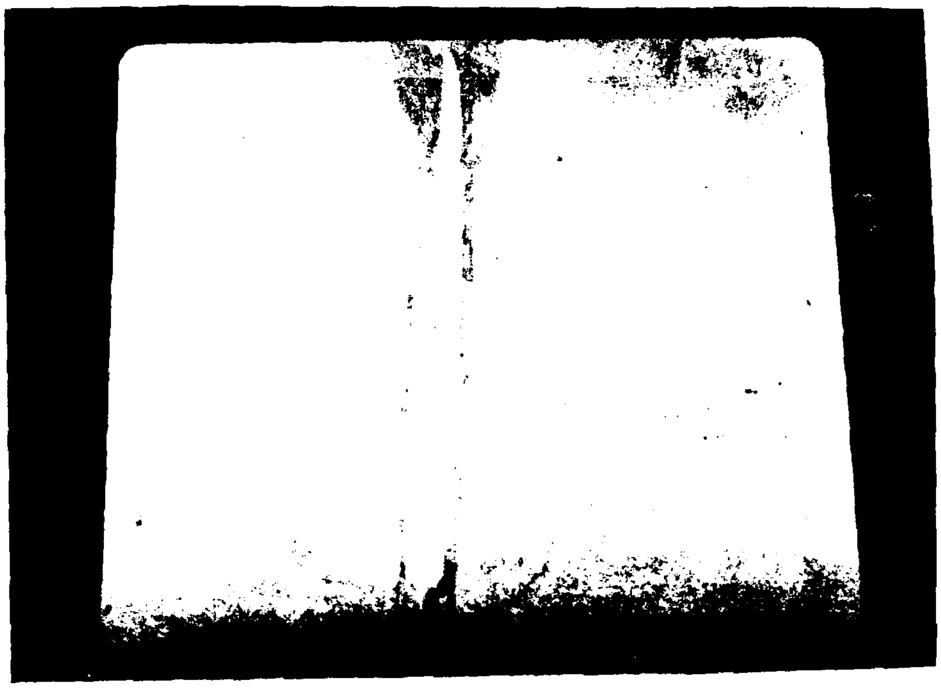


Figure 26 - Lid after 96 hours Salt Spray

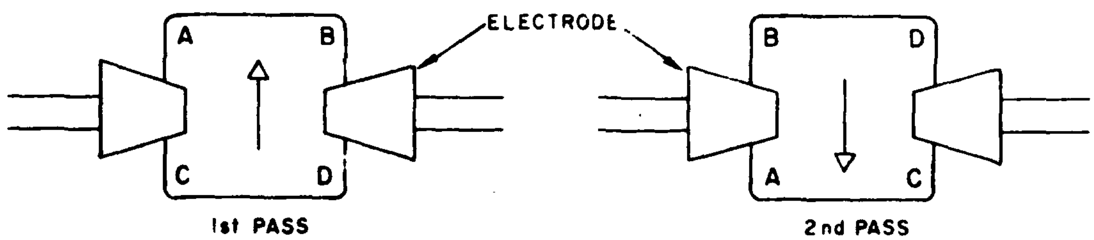
### 9.3.1 Elimination of Arcing During Electrode Roll-On

The arcing during roll-on was eliminated by introducing a time delay between electrode contact and application of weld current. The following sequence was developed:

1) Electronically sense the contact of both electrodes, i.e., the short circuit between the electrodes produced by the package.
2) Electronically delay start of weld one second. During this period, the electrodes are lifted as they roll onto the package, contacting first the seal frame and then the lid.
3) Apply weld current. At this point, both electrodes are contacting the upper edge of the lid. Arcing can no longer result from the transition of contact from seal frame to lid.

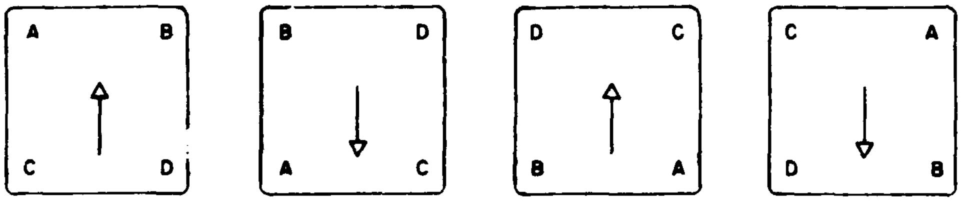
Although this procedure solves the problem of roll on arcing, it introduces another problem: insufficient weld beam overlap at the roll on corners. Under normal parallel-seam welding techniques, first one set of parallel sides is welded as the package travels under the electrodes in a direction away from the operator. After rotating 90 degrees counterclockwise, the package travels under the electrodes toward the operator, thereby welding the other two parallel sides. Let the four corners of the package be designated A, B, C, and D, as shown in Figure 27. It can be seen from Figure 27 that each of the four corners has a different roll on/roll off sequence. It can also be seen that elimination of welding during roll on will not affect corner D; will probably cause corners B and C to leak, and will surely cause corner A to leak.

The solution to this problem was found in extending the sealing procedure to include a third and fourth pass under the electrode, with the package rotated 180 degrees from the original orientation. The results are tabulated in Figure 28. Note that each corner experiences two roll offs and




| CORNER | FIRST PASS | SECOND PASS |
|---|---|---|
| A | ROLL-ON | ROLL-ON |
| B | ROLL-ON | ROLL-OFF |
| C | ROLL-OFF | ROLL-ON |
| D | ROLL-OFF | ROLL-OFF |

Figure 27 - Parallel Seam Sealing Sequence




| CORNER | FIRST PASS | SECOND PASS | THIRD PASS | FOURTH PASS |
|---|---|---|---|---|
| A | ROLL-ON | ROLL-ON | ROLL-OFF (SIDE A-C) | ROLL-OFF (SIDE A-B) |
| B | ROLL-ON | ROLL-OFF (SIDE A-B) | ROLL-OFF (SIDE B-D) | ROLL-ON |
| C | ROLL-OFF (SIDE A-C) | ROLL-ON | ROLL-ON | ROLL-OFF (SIDE C-D) |
| D | ROLL-OFF (SIDE B-D) | ROLL-OFF (SIDE C-D) | ROLL-ON | ROLL-ON |

Figure 28 - Extended Sealing Sequence

that the two roll offs proceed from different sides. Complete overlap is thus possible although welding is done only at roll off. Moreover, the weld history is now identical for all four corners.

### 9.3.2 Elimination of Arcing During Electrode Roll-Off

To prevent arcing of the electrodes during roll-off, the weld current must be switched off prior to breaking of mechanical contact. Moreover, the procedure described in Subsection 9.3.1 requires that the weld bead be extended at least halfway around a corner during roll off. In other words, the weld beads produced by the two roll offs must overlap each other. Hence, the turn-off of weld current is bracketed between two other events: 1) electrode contact having progressed past the 45 degree point, and 2) breaking of mechanical contact.

### 9.3.2.1 Analysis of Electrode Drop During Roll Off

The electrodes drop vertically as they roll off the package. It was decided to exploit this movement, to automatically turn off the weld current at the proper moment. It was anticipated that a microswitch tripped by the vertical displacement of an electrode could generate a control signal for the power source of the seam welder. To implement this sensing scheme, an understanding of electrode movement during roll off was required. This in turn presented a problem in three-dimensional analytic geometry.

The surface of the welding electrode is a portion of cone. This cone may be described by the equation:

$$x^2 + z^2 = (R_e - y \tan \theta)^2 \tag{1}$$

where

| | |
|---|---|
| $x, y, z$ | are the cartesian coordinates |
| $\theta$ | is the taper angle of the electrode |
| $R_e$ | is the radius of the electrode |

The coordinate system chosen assumes electrode rotation about the y-axis. The package is assumed to travel in the direction of the x-axis. Furthermore, the side of the package (more precisely, the edge of the lid on the package) is assumed to be a line defined in three dimensions by:

$$\begin{aligned} z &= -R_e \\ y &= 0 \end{aligned} \tag{2}$$

Inserting the condition $y = 0$ into Equation (1) results in:

$$\begin{aligned} x^2 + z^2 &= R_e^2 \\ y &= 0 \end{aligned} \tag{3}$$

These two equations define a circle in the x-z plane, centered at the origin, and of radius $R_e$. This circle is visible in parallel-seam sealing as a narrow band of discoloration around the electrode. The discoloration is caused by the contact between the electrode and the straight edge of the lid.

Inserting the additional condition $z = -R_e$ into Equation (3) results in:

$$x^2 + R_e^2 = R_e^2 \tag{4}$$

or

$$x = 0$$

Hence, the point of contact between the electrode and the side edge of the lid occurs at the coordinates $x = 0$, $y = 0$, $z = -R_e$. The physical interpretation is that contact occurs directly below the electrode axis.

The situation is more complicated at the lid corner, especially if the corner has a radius. Let this radius be equal to $R_1$. Since the surface of the lid lies in a plane parallel to the x-y plane, the corner of the lid may be taken to be one quadrant of the following circle:

$$\begin{aligned} x^2 + y^2 &= R_1^2 \\ z &= Z \end{aligned} \tag{5}$$

where Z is the distance from the electrode axis to the surface of the lid. Equation (5) is not consistent with the previous equations. Since the lid side edge was taken to be at $y = 0$ in Equation (2), the circle of Equation (5) must be moved a distance equal to its radius in the y direction.

$$\begin{aligned} x^2 + (y - R_1)^2 &= R_1^2 \\ z &= Z \end{aligned} \tag{6}$$

Equation (6) accurately describes the lid corner at one particular position; namely, the precise point at which roll-off starts. In other words, the electrode has finished welding along the package side and has just started contacting the round corner. At this point, Z is still equal to $R_e$.

To complete the mathematical model of roll-off, the lid movement relative to the electrode must be considered. This is accomplished by introducing a displacement variable, W, into Equation (6).

$$(x + W)^2 + (y - R_1)^2 = R_1^2 \qquad (7)$$

$$z = Z$$

Equation (7), together with Equation (1) (repeated here for convenience), define the mechanics of electrode roll-off.

$$x^2 + z^2 = (R_e - y \tan \theta)^2 \qquad (1)$$

As the electrode rolls off, the point of contact between the lid and electrode generates a locus in three dimensional space. The x, y, z coordinates of the locus must simultaneously satisfy Equations (1) and (7).

The dependent variable Z (elevation of electrode axis above the lid) needs to be known as a function of the other variables to implement the microswitch concept. In particular, the value of Z must be known as a function of the location of contact on the lid. In attempting to solve for Z analytically, no solution was found that yields a single point of contact between the two equations. Only intersections between the two equations were obtained, which correspond to the physical impossibility of the lid moving inside the electrode.

To arrive at a solution, a computer program was written that finds acceptable values of Z by a searching technique. In writing the program, the lid contact coordinates x, y were converted to polar coordinates because the polar angle directly states how far the weld bead has progressed around the corner. In this manner, the computer program relates the elevation of the electrode axis to degrees of corner that have been welded. Furthermore, the computer program finds this relationship as a function of three independent variables: 1) electrode radius, 2) electrode taper angle, and 3) lid corner radius.

An electrode radius of 0.170 in. and a taper of 15 degrees were known to be optimum choices for good weld beam formation along the package side. It was decided to use the computer program to investigate the third variable, corner radius. The results are plotted in Figure 29. It can be seen that the lid corner radius has little effect on electrode drop. Note that the electrodes drop only slightly before the 45 degree point, after

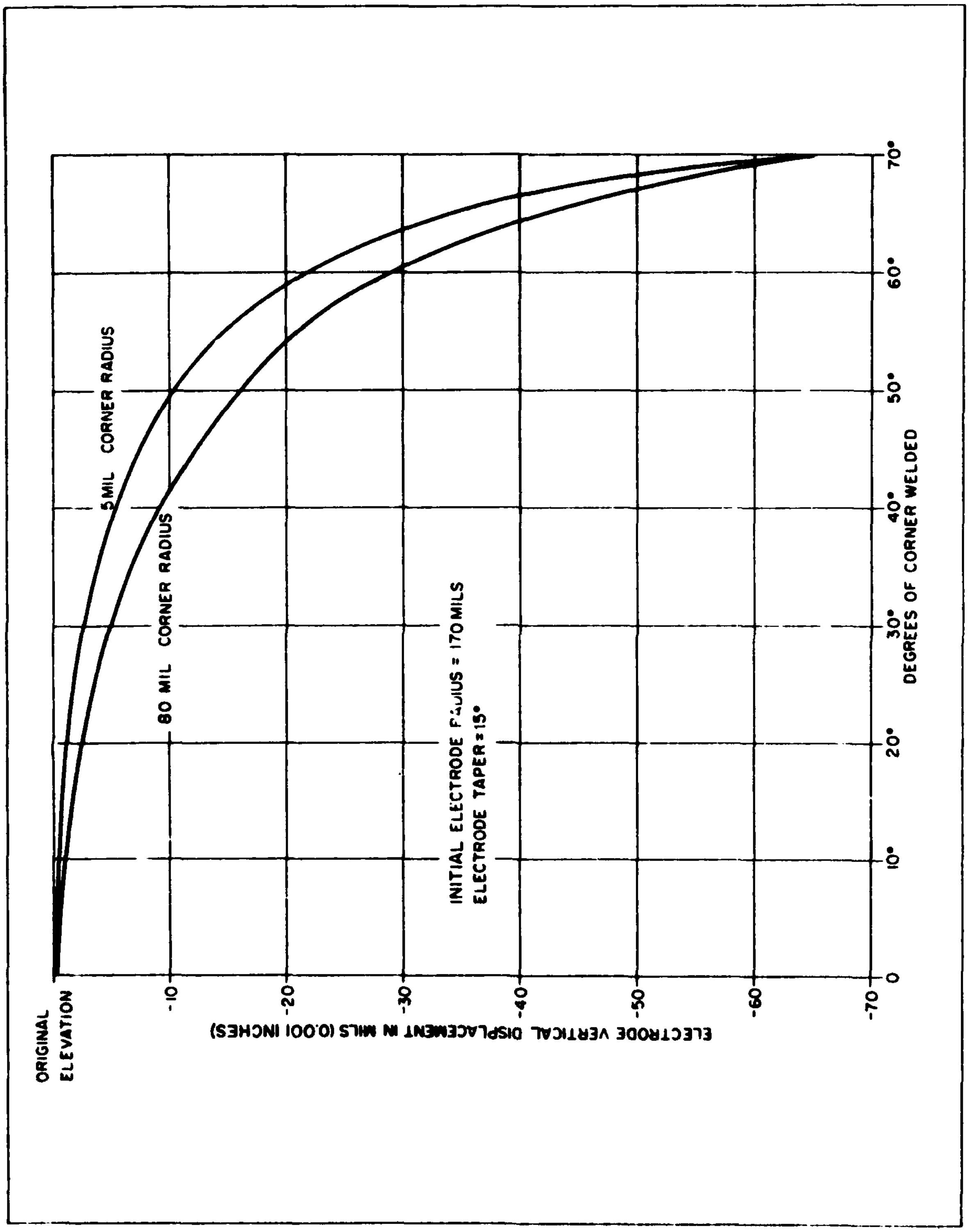



Figure 29 - Electrode Vertical Displacement versus Degrees of Corner Welded

which the drop accelerates rapidly. Hence, sensing the electrode drop with a microswitch (set to trip, for example, after a drop of 0.030 inch is a very sound technique for turning the weld current off.

In practice, the electrodes are prevented from dropping more than 0.060 inch by mechanical stops. This is done to facilitate the next roll-on. It is important to note that usefulness of the microswitch technique is not impaired by this practice.

### 9.3.2.2 Analysis of Electrode Dwell During Roll-Off

Control of dwell during roll-off is the last remaining condition that must be satisfied to prevent arcing at the corners. It was determined from analytic studies that the velocity of contact between the electrode and lid is less at the corners than at the package side. In other words, the effective feed rate is less than the actual feed rate of the package when welding the corners. This phenomenon is the result of the complex contact conditions analyzed in Subsection 9.3.2.1.

Indeed, the same basic equations and computer programs were used to analyze electrode contact velocity. The desired relationship was the contact velocity (relative to the feed rate) as a function of the degrees of corner welded. The polar coordinates of contact on the lid were obtained as before. The relative velocity was obtained as follows by first calculating the incremental arc length around the lid corner.

$$\Delta L = (R_1)\ (\Delta\phi) \tag{8}$$

where

$R_1$ = lid corner radius

$\Delta\phi$ = incremental angle in radians

By dividing the incremental arc length by the incremental package displacement that caused it, $\Delta W$, and multiplying by 100, the percentage of feed rate is obtained.

$$V\% = \frac{\Delta L}{\Delta W}\ (100) \tag{9}$$

The results of the analysis for a number of lid radii are presented in Figure 30. Several important conclusions may be reached:

1) There is a step discontinuity in the velocity of contact as the welding proceeds from the straight side to the corner.
2) By extrapolation, the contact velocity is zero at an absolutely sharp corner.
3) The larger the lid radius, the higher the initial velocity going into the corner. An infinitely large corner radius would correspond to a continuation of the straight side, and hence, the velocity would remain at 100 percent.
4) The velocity continues to drop off as the contact point moves around the corner.
5) Since weld energy is being supplied by the electrodes at a steady rate, and the feed rate is effectively reduced, the weld energy is concentrated. Hence, burning, arcing or "blow-out" is likely to occur, especially when a small corner radius is specified.

The first phase of this program used corners with a radius of 0.003 inch; significantly, corner "blow-out" was experienced. For the second phase of the program, a corner radius of 0.061 inch was selected for two reasons: 1) a sufficiently high contact velocity is maintained at the corner, and 2) tooling and experimental packages were available with this radius. Corner "blow-out" was completely eliminated.

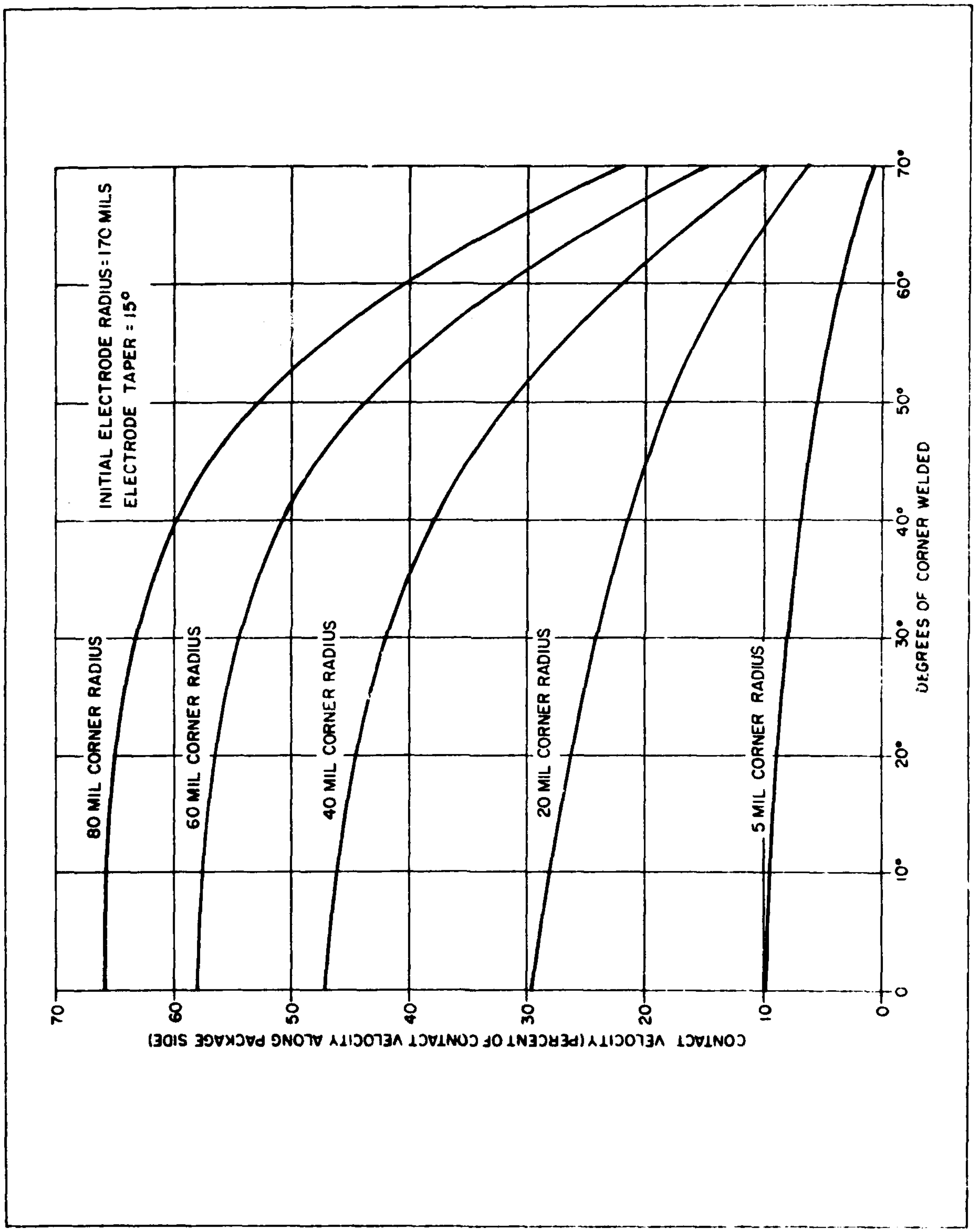



Figure 30 - Contact Velocity versus Degrees of Corner Welded

### 9.4 Verification of Parallel-Seam Sealing

The improvements in package design, lid design, and sealing technology were verified by parallel-seam sealing 200 packages. Before this run, packages were sealed to establish an optimum weld schedule, to develop a systematic setup procedure, and to measure the temperature rise of the base of the package.

The run was made on the parallel sealing equipment shown in Figures 18 and 19.

#### 9.4.1 Weld Schedule

The following weld schedule was used in the run of 200 packages.

| | |
|---|---|
| Feed Rate | 0.080 in./s |
| Weld Current | |
| Frequency | 1 kHz |
| Amplitude | 825A peak-peak |
| Pulsewidth | 20 ms |
| Pulse Repetition | 60 ms |
| Electrode Force | 190g (each electrode) |

The schedule parameters, with the exception of the amplitude, are standard settings used in parallel-seam sealing. The amplitude was optimized for this particular lid package combination. Amplitudes as low as 750 and as high as 900 produced equally satisfactory results; the median value of 825 was chosen.

The weld produced by this schedule may be seen in Figure 31, which presents a metallographic section through the lid and seal frame. Several conclusions may be drawn from the section.

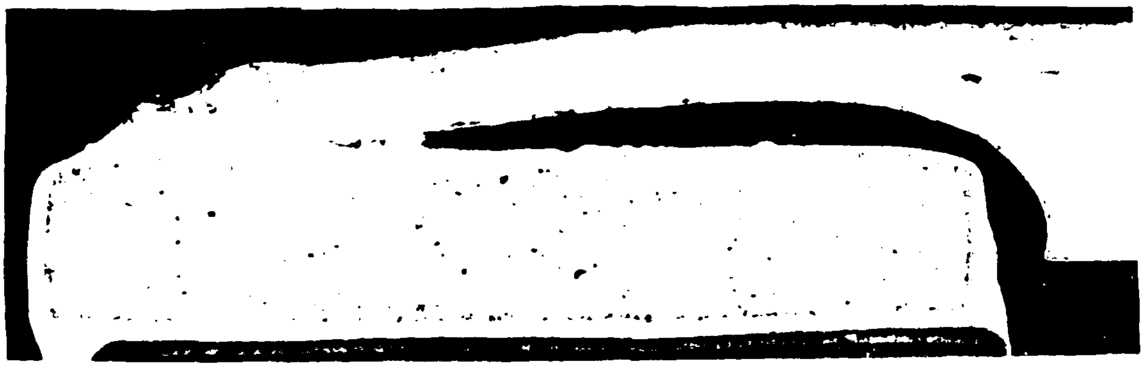


Figure 31 - Metallographic Section of the Package-Lid Weld (100X)

1) The width of the weld bead is 0.012 in. (minimum).
2) The weld produced is nickel-nickel.
3) The weld bead is nonporous, and hence, consistent with hermeticity.
4) The lid flange is deflected by the electrodes to conform to seal frame. Camber in the order of several mil/inch does not cause adverse effects.

### 9.4.2 Parallel-Seam Sealer Setup

The following mechanical setup procedure was used. The steps are explained in terms of the requirements discussed in Subsection 9.3.

1) Turn weld power off. Place a lid onto a package and feed the package halfway under the electrodes.
2) Bias the electrodes, i.e., set the electrodes so that one electrode contacts the lid edge at a larger radius than the other electrode. The electrode to which the vertical sensing microswitch is attached should contact at the smaller radius, to cause it to drop at a faster rate.

3) Adjust the mechanical down stop on each electrode so that contact to the lid is just broken. This condition is readily obtained with the aid of an ohmmeter. From this reference point, adjust the stops for a maximum electrode drop of 0.060 inch. This provides enough drop for microswitch actuation, but not enough to cause roll-on difficulty.
4) Adjust the microswitch bracket to the point where the switch is at the trip point; from this reference point, adjust the bracket so that the switch trips at the 0.030 to 0.035 inch lower electrode position. This provides for the weld current turn-off.
5) Set the electronic time delay for 1.0 to 1.1 seconds. This delay provides ample time for electrode roll-on.

### 9.4.3 Temperature Rise of Package

Measurements were taken to determine the temperature rise of the package during parallel-seam welding. The measurements were taken under actual welding conditions, using the same schedule as in the run of 200 packages.

A 1/8 inch hole was drilled through the lid to permit the entry of chromel-alumel thermocouple wire. A potentiometer was used to measure the EMF of the thermocouple.

Data was taken with the thermocouple wires attached at three different locations of the package floor: center, midpoint of the side wall, and at the corner. In the latter case, the corner selected was the one experiencing the final roll-off. The maximum temperatures recorded were: center, 74°C; side, 103°C; and corner, 98°C. It should be noted that these were empty packages. The additional heat capacity and thermal impedance of a substrate would result in even lower temperatures for components.

## 9.5 Test Evaluation

The 200 packages were tested for hermeticity and resistance to corrosion per MIL-STD-883 Method 1014 Condition A and C and Method 1009 Condition A to C. The results of these tests indicate major improvement as the result of the redesign.

### 9.5.1 Gross Leak Test

Two of the packages exhibited leaks in the seal area, for a gross leak sealing yield of 99 percent. Visual inspection of the weld bead showed defects in the weld bead. Subsequent metallurgical sectioning and examination indicated that the defects were not the result of the welding, but were anomalies present in the lid prior to welding, probably etch pits.

### 9.5.2 Fine Leak Test

The packages were fine leak tested using the helium mass spectrometer technique.

The highest leak rate indicated was $1.2 \times 10^{-7}$ atm -cc/s for one package. All other packages had readings in the $10^{-8}$ range or the $10^{-9}$ range. The average reading was calculated to be $8.5 \times 10^{-9}$ atm -cc/s.

### 9.5.3 Corrosion Resistance Test

Two groups of 22 packages were tested per MIL-STD-883, Method 1009, one group for 24 hours (Condition A) and the other for 96 hours (Condition C).

Excellent results were obtained through 24 hours, as can be seen by comparing the as sealed package to the 24 hour sample in Figure 32. All these packages passed the gross leak test, and all but one had fine leak test readings in the $10^{-8}$ range or less. The one exception read $5.6 \times 10^{-7}$.

The 96 hour salt spray samples exhibited corrosion at the weld area. Three packages in the group of 22 packages failed the gross leak test. Nineteen packages passed both the fine and gross leak tests. The failure mechanism was attributed to disruption of the nickel plating on the cover.

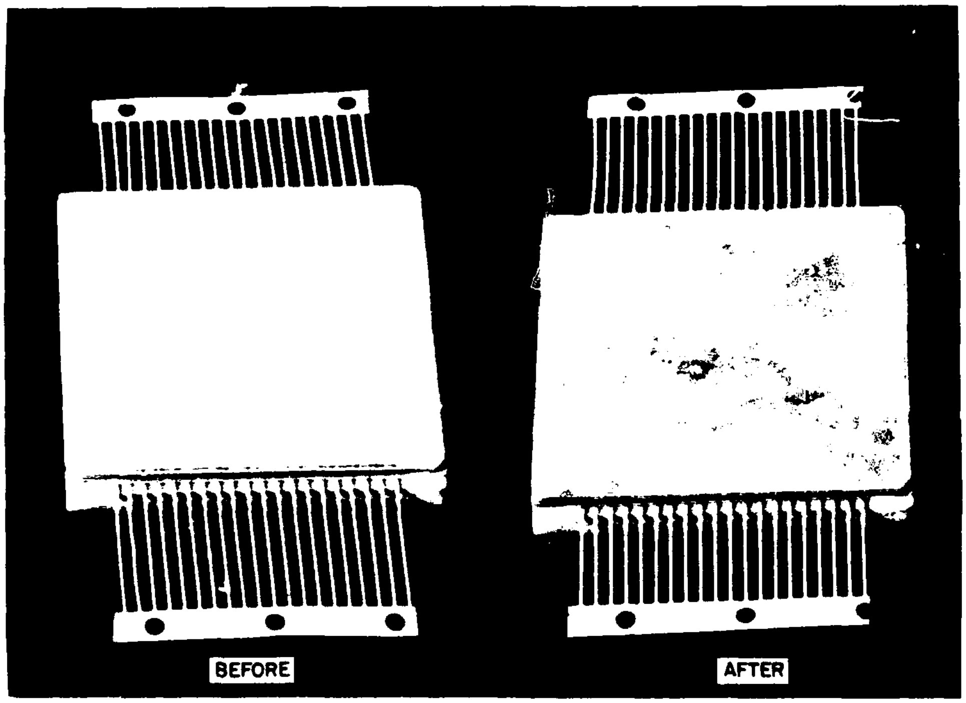



Figure 32 - Packages before and after Corrosion Test

# 10. CONCLUSION

The multilayer ceramic base and parallel seam welded packaging concept developed in this program has been shown to provide a low cost, hermetic, reliable and high yield enclosure for hybrid microassemblies. The parallel-seam weld sealing approach does not subject the hybrid circuit to high temperatures (less than 110°C for the 1 x 1 inch separable substrate package) and will provide mechanical stability and hermeticity up to 350°C.

It has been shown that the corrosion resistance of the nickel-plated F-15 alloy package lid and seal frame and the gold over nickel-plated cupro-nickel No. 725 alloy will pass the MIL-STD-883 Method 1009 Condition A (24 hours) Salt Spray Test.

High sealing yields (98.5 percent) for the hybrid microcircuit package were obtained by successful design and process integration of multilayer ceramic technology, self-locating flanged lid technology and the parallel-seam welding technology.

UNCLASSIFIED

Security Classification

**DOCUMENT CONTROL DATA - R&D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Raytheon Company<br>Missile Systems Division<br>Bedford, Massachusetts | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED<br>2b. GROUP |

3. REPORT TITLE

ADVANCED INTERCONNECTIONS AND PACKAGING TECHNIQUES FOR INTEGRATED CIRCUITS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report 1 April 1970 to 31 December 1971

5. AUTHOR(S) (Last name, first name, initial)

Ilgenfritz, Robert W.
Keohane, John S.
Walter, Dieter W.

| 6. REPORT DATE | 7a. TOTAL NO OF PAGES | 7b. NO OF REFS |
|---|---|---|
| June 1972 | 90 | 0 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO<br>DAAB07-69-C-0472<br>b. PROJECT NO<br>1H6-62705 A-440<br>c. Task 01<br>d. Subtask 18 | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>BR-6795<br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)<br>ECOM-0472-F |

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|---|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY<br>U.S. Army Electronics Command<br>Fort Monmouth, N.J. (AMSEL-TL-IA) |


13. ABSTRACT The purpose of Part I (Sections 1 through 5) of this program was to design, develop, fabricate, and test advanced interconnection and packaging techniques for complex hybrid microassemblies. The vehicle for accomplishing this objective was a package which accommodates a 1 x 1-in. working area, permits hermetic sealing without damaging the microcircuits mounted within this working area, and structurally withstands operating temperatures ranging to 350°C. The package must demonstrate a hermeticity of $10^{-8}$ $cm^3/s$.

This contractor initiated this program by selecting an approach which takes advantage of the strength and impervious nature of fired multilayer ceramics; the adhesion and high-temperature durability of refractory metals fired in a reducing atmosphere; the hermeticity of welded metal alloy covers; and the inherent reliability which results from the use of buried vias (feedthrough conductors).

Results accomplished in this study include: design and fabrication of 2 packages in which 1) a separable ceramic substrate can be attached to the floor of the multilayer ceramic base with a metal lid sealed to the base and 2) a metallized multilayer ceramic substrate with the metal lid sealed directly to the base; evaluation of laser, electron beam and parallel-seam welding sealing methodologies; development of production processes for the cover fabrication, attachment of the separable substrate, thermocompression chip and wire bonding and package assembly; and a reliability evaluation of the developed packages.

Finally, in Part 2 (Sections 6 through 10) of this program, the separable ceramic substrate package and lid were redesigned and the parallel-seam welding process was modified to "optimize" the sealing yield and corrosion resistance of the 1 x 1 in. working area hybrid circuit package. A 98.5 percent sealing yield was obtained for this redesigned parallel-seam welded package.


DD FORM 1 JAN 64 1473

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| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Integrated Circuits | | | | | | |
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